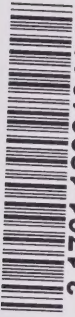


EXHIBIT

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DRAINAGE AND EROSION CONTROL MEASURES

DESCRIPTION AND PROPOSED DESIGN PRINCIPLES

Northern Engineering Services Company Limited

CALGARY ALBERTA



ENGINEERS FOR

Arctic Gas

March 1975

Canadian Arctic Gas Study Limited
1070 Calgary House
100 - 10th Avenue, S.W.
Calgary, Alberta
T2P 1G1

DRAINAGE AND EROSION

CONTROL MEASURES

DESCRIPTION AND PROPOSED DESIGN PRINCIPLES

Dear Mr. Smith,

We are pleased to submit this report which describes the drainage and erosion control measures recommended for the Arctic Gas project.

The report develops methods for detailed right-of-way design and control in drainage and erosion control. Although the design with the various regulatory agencies stated the measures that will be employed, the design computer program was preliminary and was general for design purposes. In this report the various hydrologic, hydraulic, and erosion factors relevant to erosion control are integrated to provide a detailed basis for design and construction of erosion control measures.

Prepared for

Canadian Arctic Gas Study Limited

By

Northern Engineering Services Company Limited

Calgary, Alberta

March 1975



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3 March 1975

Canadian Arctic Gas Study Limited
1270 Calgary House
550 - 6th Avenue, S.W.
Calgary, Alberta
T2P 0S2

Attention: Mr. D.J. Stark
Project Manager

Reference: 1.8.35 Drainage and Erosion

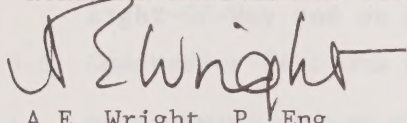
Dear Mr. Stark:

We are pleased to submit this report which describes the drainage and erosion control measures recommended for the Arctic Gas project.

The report develops methods for detailed right-of-way design with respect to drainage and erosion control. Although the filings with the various regulatory agencies listed the measures that will be employed, the design categories therein were qualitative and too general for design purposes. In this report the various hydrologic, hydraulic, and economic factors relevant to erosion control are integrated to provide a rational basis for design and example design curves are generated.

Yours very truly,

NORTHERN ENGINEERING SERVICES COMPANY LIMITED



A.E. Wright, P. Eng.
Project Manager

EDS/ny

PROJECT 1.8.35
DRAINAGE AND EROSION
CONTROL MEASURES

CANADIAN ARCTIC GAS STUDY LIMITED
CALGARY ALBERTA

DESCRIPTION AND PROPOSED
DESIGN PRINCIPLES

DATE

MARCH 1975

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PROJECT 1.8.35
DRAINAGE AND EROSION
CONTROL MEASURES

CANADIAN ARCTIC GAS STUDY LIMITED
CALGARY ALBERTA

DESCRIPTION AND PROPOSED
DESIGN PRINCIPLES

DATE MARCH 1975

1. SUMMARY

This report describes the measures which will be used for drainage and erosion control for the pipeline right-of-way, access roads, and other ancillary facilities. Breaks in the backfill mound, diversion dikes, drainage ditches, ditch plugs and other common construction procedures are recommended. The report notes where changes in methods are required for arctic conditions.

Because it is generally uneconomical to design for the maximum possible runoff, which occurs extremely rarely, methods are developed in the report for selecting the most appropriate control measures for a given section of the proposed alignment. The analysis includes hydrologic, hydraulic and economic considerations. Example design curves are generated.

Sample calculations indicate:

- a. Mound breaks are only appropriate for very small streams (drainage areas of the order of 0.1 square mile). Channels draining larger areas will require minor stream crossings.
- b. The high cost of repair in northern regions results in a design storm of a very high return period. Because of the small areas concerned, the design storm is generally a short, intense, rare rainstorm.

PROJECT 1.8.35
DRAINAGE AND EROSION
CONTROL MEASURES

CANADIAN ARCTIC GAS STUDY LIMITED
CALGARY ALBERTA

DESCRIPTION AND PROPOSED
DESIGN PRINCIPLES

DATE

MARCH 1975

2. INTRODUCTION

Control of accelerated erosion and drainage in the vicinity of the pipeline ditch and right-of-way is necessary both to maintain the integrity of the pipeline and ancillary facilities and to minimize detrimental environmental effects. Proper design and construction techniques will be required, for example, to reduce the risk of exposure of the pipe and sedimentation in streams due to gullying on or off the right-of-way. Care will also be required to minimize alteration of sub-surface and surface drainage patterns that might have deleterious effects on plant and animal habitats or aggravate slope stability, frost heave and thaw settlement problems.

General considerations and control measures for protection of the pipeline right-of-way, access roads, compressor stations and other facilities are outlined in sections 8b.1.3.8.1 and 8b.1.3.8.4.1 of the DIAND and NEB application and section II.D.2.1 of the FPC filing. Copies of the former are included as Appendix 1 of this report. In essence, drainage and erosion will be controlled by a combination of preservation of existing vegetation during construction, revegetation programs, and construction of various runoff control structures. Given the construction and revegetation programs which will be applied to a particular section of the right-of-way and the length of time until revegetation becomes

effective, this report discusses the methods which will be used to design the control structures.

Section 3 augments the aforementioned articles with a more detailed description of the proposed right-of-way configurations. Section 4 gives the background to the preliminary assignment of control measures on the alignment sheets. Section 5 describes the philosophy proposed for final design and Section 6 demonstrates the type of analyses which will be used in support of the proposed design methods.

3. DESCRIPTION OF CONTROL MEASURES

3.1 Proposed Measures Along the Pipeline Right-Of-Way

This section summarizes the various construction procedures that will be used to protect the pipeline ditch and right-of-way against undue erosion. During construction ditch spoil will generally be mounded over the ditch to allow for settlement of the backfill. In some situations erosion control measures will be required to protect this mound, to prevent gullyng or washouts on other parts of the right-of-way, to eliminate ponding on and adjacent to the right-of-way, and to confine, where practical, significant alterations of natural flow patterns to the right-of-way.

The degree of protection required on a section of the alignment depends primarily on the maximum rate of runoff it is expected to intercept, the slope and cross slope angle of the pipeline ditch, and the erodibility of the soils present. Selection of the measures appropriate for a given section of the alignment is a final design exercise and will be based on techniques similar to those described in Sections 5 and 6. The following sections are restricted to a physical description of the various methods which may be used.

3.1.1 Backfill Mound Breaks

Where ponding upslope of the pipeline ditch is determined to be detrimental or where potentially erosive surface runoff must be directed across the ditch, breaks, generally 5 to 12 feet wide,

will be left in the backfill mound (Figures 1, 2, and 3). The surface of the break and the slopes of the backfill mound will be protected by a layer of non-erodible material adequate to withstand anticipated surface flows. A regular inspection and maintenance program will be required to ensure that thaw settlement or frost heave do not render critical mound breaks ineffective.

3.1.2 Ditch Plugs

When erosion of the backfill from water flowing through the ditch is possible, impervious ditch plugs will be provided across the ditch (Figure 2). The plugs will be constructed of impervious materials placed either in sacks or between forms and keyed into the walls of the pipe ditch to prevent seepage around the sides.

3.1.3 Diversion Dikes

Diversion dikes will be used where necessary to divert runoff parallel to the ditch across or away from the right-of-way or to intercept runoff upslope of the pipeline.

In ice-rich permafrost subject to thaw settlement diversion dikes will be constructed of sand bags or of pit run materials placed on the organic mat. In thaw stable permafrost and in non-permafrost areas, the dikes will be constructed of soil and vegetation debris excavated from the drainage ditches in a single bulldozer pass (Figure 3).

Dikes, where required to direct flow across the right-of-way, will be oriented obliquely to or normal to the pipeline on both sides of the right-of-way, will generally be associated with a mound break, and will be extended 10 to 20 feet into the uncleared ground adjacent to the right-of-way (Figures 1, 2, 3, and 4). The location and orientation of the diversion dikes will be determined in the field prior to and during construction.

On some steep slopes, such as river banks, cut grading may be required. In such situations, the right-of-way surface after construction may be below natural grade and diversion of surface runoff away from the right-of-way may not be practical. In such cases, diversion dikes may be used to terrace the exposed face (Figure 4).

3.1.4 Drainage and Interception Ditches

In non-permafrost and thaw stable permafrost terrain, drainage ditches may be used as adjuncts to the diversion dikes where large flows which could cause widespread flooding and erosion upslope of the backfill mound are anticipated. In erodible soils the ditches will be protected by a layer of non-erodible material.

In general, ditches will not be used in permafrost terrain where thermal degradation could follow surface disturbance. An exception to this is where a ditch is required to drain ponded surface water which may lead to thermokarst activity. If ditches are necessary in such areas, a wide shallow configuration will be used, prefer-

ably formed by deliberately causing minor disturbance to vegetation, to deepen the active layer and initiate a limited amount of thaw settlement. Ditches formed in this manner will retain their natural vegetative cover, and being wide and shallow will minimize the possibility of continued thermal erosion. A number of passes of a tracked vehicle after removal of the snow cover will cause sufficient disturbance to the ground surface to produce the required permafrost regression.

3.1.5 Flow Obstructions

In steeply sloping areas of high runoff, trees and shrubs from clearing operations will be placed to form dispersion barriers as required. Where sufficient debris from the clearing operations is available and where concentrated flows persist in spite of the riprap at the break in the backfill mound, downslope obstructions such as rocks and gravel may be located in the path of the potentially erosive flow. In areas of high risk of erosion the clearing debris may also be windrowed on the upslope edge of the right-of-way (Figures 1 and 2).

3.1.6 Granular Berms

Where erosion of the backfill by flow parallel to the mound could occur, the upslope face of the mound will be protected with a layer of non-erodible material (Figures 2 and 3).

3.1.7 Granular Cap

In some circumstances, concentration of flow through the mound

breaks may be undesirable. In such cases, a pit run sand or gravel cap will be added to the ditch backfill. The cap, illustrated in Figure 3, will extend below the ground surface to the anticipated thickness of the active layer and will be mounded above grade to compensate for the settlement of both the granular material and the underlying native backfill. This cap will present an erosion resistant surface allowing passage of surface and subsurface flow across the ditch. Breaks in the granular mound will be provided to allow excess water to cross the ditchline.

Excess spoil will be spread in areas not affected by surface drainage, and revegetation measures may be applied.

3.1.8 Gabion Protection

Gabion protection may be used across the breaks formed in the backfill mound when the amount of settlement is difficult to estimate but is anticipated to be severe. Gabions are commonly used in river training and bank protection works. The gabion, illustrated in Figure 3, consists of two layers of wire mesh laid across the surface of the backfill mound and the adjacent undisturbed surface, enclosing a layer of coarse gravel and cobbles. The gabion will readily deform to the surface of the backfill for any amount of settlement.

3.2 Proposed Measures Along All-Weather Access Roads

Drainage and erosion control measures for permanent and temporary access roads (Figure 5) will, in general, follow those currently in

use in highway construction, (American Iron and Steel Institute, 1971), and along logging trails in non-permafrost areas (Packer and Christensen 1964, Packer 1967) with appropriate modifications in permafrost regions.

3.2.1 Bridges and Culverts

The usual practice in non-permafrost areas of intercepting drainage and channelling it in concentrated flows through culverts at maximum spacing will be modified by providing more culverts at closer spacing (Lostpeich 1971).

Where natural drainage is transverse to the road, the upslope side of the embankment will be protected from erosion by flow parallel to the road by a layer of non-erodible material. Downstream from culverts on steep cross-slopes diffusers, consisting of logs, clearing debris, rock or coarse pit-run gravel, will be provided. Where the road centerline parallels the dip of the natural ground slope to within about 10° culverts may not be required. In this situation, however, diversion dikes similar to those proposed for the pipeline right-of-way under similar slope conditions, will be used to divert excess water off the cleared right-of-way.

3.2.2 Culverts for Fish Passage

Roadways will be located to avoid major streams. If it is necessary to cross a stream which supports an identifiable fish migration, culvert designs will be modified accordingly. Considerations which will influence design are given in Appendix 2.

3.2.3 Cross Ditching

Cross ditching across the surface of the road may be used as an alternative to culverts where the road crosses numerous poorly defined drainage courses. Where cross ditching is used the upper foot of the road surface on both sides of the ditch will be protected with riprap or coarse granular material to prevent headward gully erosion. Downstream obstructions will be used to trap sediment transported by the running water and to disperse flow. Cross ditch spacing will depend on the gradient and on the road surface material. Spacings will generally range between 75 and 150 feet. Cross ditches are illustrated in Figure 5.

3.2.4 Side Ditching

Side ditches will be used to intercept drainage upslope of the road embankment and to channel it to a culvert or cross ditch. In permafrost areas where the underlying soils are susceptible to thaw settlement, the use of excavated side ditches will be minimized and the technique of forming wide shallow ditches, by carefully controlled compaction of the surface after removal of most of the snow, will be employed. Ditch blocks will also be used where necessary to reduce the flow velocity.

3.3 Proposed Measures Along Snow Roads

The use of winter roads will be limited to those periods when a compacted snow or ice wearing surface can be constructed and maintained. Right-of-way preparation for winter roads will be limited largely to the removal of trees and larger shrubs, and will result

in minimum disturbance to the surface organic layer. The surface vegetative cover will therefore, provide erosion protection. In general, no additional drainage and erosion control measures will be required. If thaw settlement that would lead to diversion of existing drainage along the cleared winter road is anticipated, diversion dikes will be used to intercept such flows and direct them into the undisturbed areas at the edge of the cleared area.

3.4 Proposed Methods of Preventing Icings on the Pipeline Right-Of-Way and on All-Weather Roads and Airstrips

In locations where detrimental icings occur, installations will be protected by intercepting flow upslope and directing it away from the affected facility. This may be accomplished by a cut-off barrier of sheet piling or other impervious material (Figure 6). Adequate facilities will be provided to allow the melt water from icings to dissipate in spring without causing erosion. Since a cut-off barrier will force groundwater seepage to the surface during the summer, the barrier will be constructed of material that will resist this flow.

Where the aquifer can be interrupted below the seasonal frost layer, subsurface drains may be used.

To provide adequate capacity in case of icings at culverts, at least two pipes will be provided at each location. The lower one will be located at ground surface, with the bottom of the second pipe set above the invert of the second. Where potentially severe

icing conditions are identified, additional pipes will be provided in a staggered configuration at horizontal spacings greater than the pipe diameter.

3.5 Compressor Stations and Other Ancillary Facilities

Ancillary facilities, such as compressor stations and wharf sites, are of limited areal extent and will cause only local interference to existing drainage patterns.

Drainage and erosion control measures will be similar to those proposed along the pipeline right-of-way and for access roads. Diversion dikes and, where necessary, drainage ditches will be used to divert surface and subsurface flow around smaller facilities such as helicopter pads and compressor stations. Culverts, icing controls, diversion dikes, and ditches may be required for airstrips. Where possible, compressor stations have been proposed in areas where culverts will not be required.

4. PRELIMINARY DESIGN CATEGORIES

With the climatological, hydrological, and geotechnical data available at this time, it is not realistic to design detailed drainage and erosion control measures for each segment of the pipeline route. Detailed design will be carried out prior to and during construction when information necessary for a definitive design will be available. Modifications will be made to the various control measures after construction based on observations of their effectiveness.

On the alignment sheets, each segment of the pipeline has been assessed with respect to drainage and erosion problems and has been assigned to one of eight drainage and erosion control categories. These categories, summarized in Appendix 1, are based on the following factors:

- a. Average surface slope and slope length along and across the right-of-way,
- b. Terrain type (which defines the soil type at ground surface),
- c. Existing drainage patterns.

5. DESIGN PHILOSOPHY FOR THE PIPELINE RIGHT-OF-WAY

5.1 Introduction

This section describes, in general terms, some of the principles which will be used to select drainage and erosion control measures for a given section of the alignment. Except for special cases, all segments of the route will be assigned to design categories for which general rules will be developed.

In southern regions many guidelines for erosion control are already available. These are based largely on local experience, and consequently are applicable only to a limited range of conditions. Since only limited experience is available in northern Canada, new guidelines must be developed from basic analytic studies of the hydrologic conditions and the erosion process. The types of analytic studies required include:

- a. Climatological studies to develop regional probabilistic models of rainfall and snowmelt events.
- b. Hydrologic studies to develop rainfall/snowmelt runoff models to transform climatological statistics to runoff statistics.
- c. Hydraulic studies to establish erodibility of various backfill configurations.
- d. Cost studies to determine optimum design of control measures.

The discussion that follows is limited to the pipeline right-of-way. Similar principles, requiring the same types of information, will be applied to roads and ancillary facilities.

5.2 Erosion

The primary requirement of any erosion control structure will be to direct any potentially erosive flows safely across or away from the pipeline right-of-way. This will be accomplished by leaving breaks in the backfill mound, lined with select backfill, and various configurations of diversion dikes and drainage ditches to control anticipated flows.

Mound breaks will be required at most low points along the right-of-way, and at small identifiable drainage channels. The breaks will be designed for a maximum scour under design flow conditions of 2.5 feet. If deeper than minimum burial is required to protect the pipe, the channel will be classed as a minor stream and an appropriate design provided. This restriction limits the size of catchment area of concern for erosion control design to the order of 0.1 square miles (see Appendix 3).

Mound breaks will also be provided on slopes where additional protection of the backfill mound is required.

The design and spacing of the erosion control structures will depend on the flow that will be intercepted by the right-of-way. This flow is a random quantity having some high, but rarely occurring, upper limit. It will be uneconomical to design for this maximum possible flow and some lower value will be used, determined by an analysis of construction, repair and maintenance costs.

Since the cost of repair is generally much higher than the cost of construction the optimum design flow will usually be some high, infrequently occurring value.

Flows concentrate quickly on small catchment areas. Consequently, the peak flows that result from storm events are virtually independent of storm duration and can be estimated from storm intensity. Since the intensity of even a moderate rainstorm will exceed the intensity of a snowmelt event, analysis of runoff will generally be restricted to rainfall events. Furthermore, extreme rainfall intensities are frequently associated with short duration storms. Therefore, rainfall records of short sampling intervals, such as hourly data, will be required.

5.3 Drainage

The breaks in the backfill mound necessary for erosion control will also provide drainage for surface runoff. In some instances, however, additional measures may be required for control of subsurface flow.

Operation of the pipe at temperatures below 32°F in permafrost regions will result in a decrease in the thickness of the active layer up to 1.5 feet directly over the pipeline. This will restrict movement of subsurface water across the right-of-way and may result in the diversion of a portion of the flow towards low points along the alignment, raising the water table at these locations. This rise will be countered at these points by an increase in the depth of the active layer due to the increased convective heat transfer

across the pipeline ditch. The net rise of the water table at low points will, therefore, be significantly less than 1.5 feet. Ponding will be localized and generally the effects will not extend beyond the right-of-way.

When ponding at low points is a concern, select backfill of specified minimum permeability will be used in the construction of backfill mound breaks.

The diversion of a portion of subsurface flow along the right-of-way will have only a minor effect on soil water conditions downslope. This effect will be minimal since other components, namely infiltration from rainfall and snowmelt and meltwater from permafrost, will replenish the soil-moisture reservoir.

In areas where the diverted component is identified as environmentally significant, this flow will be maintained by using select material of appropriate permeability for the seasonably thawed portion of the backfill.

5.4 Forest Fires

No portion of the alignment is immune to fire. However, the chance is small that a fire would cross the right-of-way with sufficient intensity to completely destroy the vegetation cover. If this does occur, the erosion control protection measures already in existence

will assist in minimizing erosion. If inspection shows they are inadequate, additional measures will be constructed as required.

5.5 Icings

In general, icings occur whenever flow in an aquifer is restricted and forced to the surface during a period when air temperatures are below freezing. The supply to the aquifer must be from a source which is active during such periods, such as sub-permafrost groundwater or a lake which does not freeze to the bottom.

Since the presence of icings adds to the cost of winter construction, and could interfere with maintenance operations, areas known prone to icing will be avoided where practical. Should detrimental icings persist along the right-of-way, access roads, or other facilities, control measures described in Section 3.4 will be implemented.

5.6 Identification of Drainage Channels

Successful design of drainage and erosion control measures will rely on the accurate identification of all significant drainages crossed by the pipeline. Generally, topographic information from maps, orthophotomosaics, or aerial photography will be adequate. However, portions of the route cross stretches in which drainage patterns are poorly defined and frequently obscured by vegetation. In such areas, the feasibility of using low-level coloured infra-red photography is under investigation. It appears that drainage patterns can be identified, particularly during relatively dry periods, by differences in plant cover and soil moisture conditions.

5.7 Revegetation

Progress in studies toward revegetation of the pipeline right-of-way are described in Dabbs et al. (1974) and Younkin et al. (1974).

Revegetation and erosion control are intimately related. For example, erosion control measures must be designed for bare soil conditions until vegetation becomes effective. In southern regions this period may be a few weeks, whereas in northern regions several years may be required.

When balancing the erosion control and revegetation programs in northern regions the following factors will be considered:

- a. The erosion control program will generally be less costly if revegetation can be established quickly.
- b. Native species will reinvade disturbed areas, but in most northern areas the invasion may take longer than desirable.

In such cases non-native grasses, which are faster establishing but short lived in arctic conditions, will be used to provide short term protection. Usage of non-native species will be minimized, however, to ensure re-establishment of native communities as soon as practical.

6. EXAMPLE DESIGN ANALYSIS

6.1 Introduction

This section illustrates by means of an example the type of analysis that can be employed to develop guidelines for design situations. When the pipeline descends or ascends a long slope, for example, granular protection (Section 3.1.6) and/or mound breaks (Section 3.1.1) may be required to protect the backfill mound and the right-of-way. The best combination of the two forms of protection depends on the complex interaction of hydrologic, hydraulic and economic factors. Methods for making this selection are developed in this chapter. For a hypothetical catchment area, design curves (Figure 12), typical of curves which can be developed for the variety of situations along the pipeline route, are generated.

Basic to the analysis is a rainfall-runoff model that can be used to estimate the peak flows that will arrive at the right-of-way, given the intensity and duration of precipitation events. A flood frequency curve is then constructed by assigning a probability to each runoff-producing event using a probabilistic model of climatological data. This curve gives the annual risk of exceedence associated with each design flow which is then transformed into an assessment of the risk of erosion for each combination of mound break spacing and granular protection. Finally, economic considerations are included and an optimum design is determined.

The hypothetical catchment area crossed by the pipeline in this example is in a permafrost region near Norman Wells, N.W.T. Its characteristics are given in Figure 10. It is assumed that revegetation measures will require four years before they become effective for erosion protection. Other parameters are estimated as required for use in the example.

6.2 Flood Frequency Model

6.2.1 Introduction

This section presents a model to estimate the probability that a certain flow per unit length intercepted by the pipeline will be exceeded annually. The risk that a given flow will be exceeded depends on:

- a. climatological parameters -
 - mean intensity of precipitation
 - mean duration of precipitation
 - mean annual number of independent precipitation events
- b. upslope catchment area parameters
 - drainage area
 - length of drainage
 - slope
 - depth of the permeable layer
 - soil permeability
 - ground surface roughness

The analysis has three steps

- a. development of a precipitation-runoff model
- b. selection of a probabilistic climatological model

c. transformation of climatological statistics to runoff statistics.

6.2.2 Precipitation-Runoff Model

Figure 7 illustrates a conceptual model of a catchment area. The basin has an area A, a slope S, and a surficial soil layer with a surface roughness n, thickness b, and permeability k. Flow from the catchment area may either be subsurface or surface.

Assuming subsurface flow to be governed by D'Arcy's law, the capacity of this layer to deliver flow to the alignment is limited by:

$$q_{ss}^{\max} = kSb \quad (1)$$

where: $q_{ss}^{\max}$ = maximum subsurface flow/unit length of alignment
 k = soil permeability
 S = slope of catchment area
 b = thickness of permeable layer

The capacity of the subsurface layer to deliver flow is obtained whenever the surface layer is saturated. Since full saturation is the most probable condition during a design storm event it is reasonable to model the subsurface flow in the conceptual catchment by $q_{ss}^{\max}$ which in turn depends on the thickness of the permeable or active layer.

Assuming infiltration to be uniformly distributed areally, the infiltration rate is given by:

$$\phi = q_{ss}^{\max} / L_c \quad (2a)$$

where: ϕ = infiltration rate

L_c = length of catchment area

Substituting (1) into (2a) gives:

$$\phi = kSb/L_c \quad (2b)$$

For precipitation events of intensity greater than ϕ , excess precipitation begins to move overland down the catchment area slope. For durations greater than the time of concentration, t_c , of the catchment area, the peak flow at the alignment is given by:

$$q_s^{\max} = (i - \phi) L_c \quad (3)$$

where: $q_s^{\max}$ = peak surface flow

i = rainfall intensity

L_c = length of catchment area

For storm durations less than t_c , $q_s^{\max}$ depends on precipitation intensity and duration and the slope and roughness of the catchment area.

In this study the method developed for the Stanford Watershed Model (1966) for calculating $q_s^{\max}$ and t_c was adopted. Although approximate, the formulae provide results which agree acceptably with experiment and provide a convenient expression for the relationship between peak surface flow and precipitation intensity and duration.

6.2.3 Climatological Model

The joint probability density function of precipitation intensity and duration can be represented (Eagleson, 1972) by:

$$f(i, t_r) = (\beta\lambda/K) \exp(-\lambda t_r - (\beta i/K)) \quad (4)$$

where: i = rainfall intensity

t_r = rainfall duration

β = storm intensity exponent (inverse of mean intensity)

λ = storm duration exponent (inverse of mean duration)

K = areal reduction of point storm rainfall

$$= 1 - \exp(-1.1\lambda^{-0.25}) + \exp(-1.1\lambda^{-0.25} - 0.01 A_r)$$

A_r = direct runoff area

$$= cA_c$$

A_c = catchment area

c = a co-efficient between 1/3 and 1/2

The values of λ and β for four meteorological stations along the pipeline route are given in Table 1. These values are based on daily rainfall records and simulated snowmelt rates. For final design, hourly rainfall statistics will be used (Section 5.2).

Marginal frequency distributions of intensity and duration are shown in Figures 8 and 9 for Fort Simpson and Tuktoyaktuk.

6.2.4 Flow Frequency Analysis

Any runoff producing event will produce some peak flow, q_p . To

estimate the probability that q_p is less than some given value, q , it is necessary to evaluate the following integral:

$$F(q_p < q) = \iint_R f(i, t_r) dt_r$$

where: q = flow value

q_p = peak flow resulting from a runoff producing event

$F(q_p < q)$ = probability that q_p is less than or equal to q

R = region of integration (all values of i and t_r that generate peak flow less than q)

Since the antecedent soil moisture condition is assumed to be a saturated permeable surface layer

$$F(q_p < q_{ss}) = 0 \quad (5)$$

For rainfall intensities greater than ϕ

$$F(q_p < q) = 1 - \int_{q/L_c}^{\infty} \frac{\beta}{K} \exp\left(-\frac{\beta i}{K} - \frac{c}{i - \phi}\right) di \quad (6)$$

where: c = a function of q given by kinematic wave theory

No explicit solution for q exists and it is necessary to resort to numerical techniques. However, it can be shown that

$$\lim_{q \rightarrow q_{ss}} F(q_p < q) = 1 - \exp(-\beta i/K)$$

$$q \rightarrow q_{ss}$$

$$\lim_{q \rightarrow \infty} F(q_p < q) = 1 - \exp(-\beta q/KL_c)$$

$$q \rightarrow \infty$$

$1-F(q_p < q)$ is the probability that the peak flow resulting from a single precipitation event is greater than q . Since runoff events on small catchment areas, are generally independent the probability of exceedence on an annual basis is obtained from:

$$1-F(q_p < q_A) = 1 - F(q_p < q)^N \quad (7)$$

where: $1-F(q_p < q_A)$ = probability, in a given year, that the peak flow exceeds a value q_A

N = annual number of independent precipitation events.

For simplicity $F(q_p < q_A)$ will be written $F(q_A)$.

6.2.5 Sample Calculations

$1 - F(q_A)$ was evaluated numerically for the catchment area described in the introduction of this chapter and the results are presented in Figure 10. Since the climatological parameters available were daily averages (see Table 1), the calculated values for q_A represent maximum daily flows. In Figure 10, the flow values have been arbitrarily doubled to give more realistic estimates of maximum instantaneous flow. This was done for illustrative purposes only and is usually not necessary since estimates of hourly meteorological data would normally be used.

6.3 Calculation of Expected Erosion

Given the probable flows intercepted per unit length of the back-fill mound, it is necessary to determine when erosion can be expected.

The situation is shown schematically in Figures 7 and 11. Flow is intercepted by the backfill mound and diverted along the right-of-way until a break in the mound is reached. Some channelization of flow can be expected, especially if thaw settlement has occurred along the pipeline ditch. The designer must ensure that this channelization is not excessive and that the capacity of the mound break is not exceeded.

The flow which a mound break can sustain is determined by its width, the nature of the material with which it is lined, and the permissible depth of flow. For this analysis, it is assumed that a break flow of 20 cfs is allowable (see Appendix 3).

The geometry of flow next to the backfill mound cannot be anticipated. Consolidation and heaving of the backfill would produce a full range of ditch cross-sections which will be further modified by any intercepted flow. There may also be situations where flow will select a route away from the ditch mound, in which case the geometry of the channel is independent of ditch configuration.

Consequently, any criteria used to predict unacceptable erosion parallel to the backfill mound must be regarded as arbitrary since they are necessarily based on an assumed channel configuration. For the purposes of this exercise, it is assumed that flow will develop a shallow, parabolic channel. This is a reasonably realistic shape and permits breadth, b to be expressed as a single function of depth of flow, d :

$$b = cd^2$$

where b = breadth

d = depth of flow

c = a constant

A value for c was selected based on the observed thaw settlement parallel to the backfill mound at the Sans Sault Test Facility.

The ditch formed had $d = 0.5$ feet and $b = 2.0$ feet, which gives $c = 8.0$.

Therefore:

$$b = 8.0d^2 \quad (7)$$

The velocity that will occur in this hypothetical channel can be related to flow by the well-known Manning equation:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \quad (8)$$

where: V = average channel velocity (ft/sec)

R = hydraulic radius (cross-section of flow area
in square feet divided by wetted perimeter in feet)

S = slope of water surface (usually taken equal to
channel slope)

n = Manning's co-efficient of roughness

Using equations (7), (8) and the continuity equation:

$$Q = AV$$

where Q = channel flow

A = cross-section of flow area

the following expression can be derived:

$$Q = \frac{3.03n^{4.5}V^{5.5}}{S^{2.25}}$$

The erodibility of various soil and vegetation covers can be characterized by the velocity of flow they can withstand before movement can be expected (Chow, 1969). Typical allowable velocities are given in Table 2. Using an allowable velocity criteria, the allowable flow parallel to the backfill mound, can be approximated by:

$$Q_{all} = \frac{3.03 n^{4.5} V_{all}^{5.5}}{F_s S^{2.25}} \quad (9)$$

where: Q_{all} = allowable flow (cfs)

V_{all} = allowable velocity for soil type (ft/sec)

S = ditch slope (ft/ft)

n = Manning's roughness co-efficient

F_s = factor of safety

When the flow parallel to the backfill mound exceeds Q_{all} , there is a high probability that erosion will occur.

With reference to Figure 11, and defining

q_A = maximum flow per unit width of cross slope arriving at the right-of-way in a given year

L = distance between mound breaks

- G = length of gravel backfill
 B = mound break width
 θ = cross slope angle of ditch
 Q_1 = allowable flow - native backfill
 (given by equation 9)
 Q_2 = allowable flow - gravel backfill
 (given by equation 9)
 q_1 = $Q_1 / (L - G) \cos \theta$
 q_2 = $Q_2 / (L - G) \cos \theta$
 l_{e1} = length of eroded native backfill
 l_{e2} = length of eroded gravel backfill
 l_e = total potential erosion

the amount of erosion for a given flow event and backfill combination can be estimated by:

$$\begin{aligned}
 l_e &= 0 & 0 < q_A < q_1 \\
 l_e &= l_{e1} = (L - G) \left[1 - \frac{q_1}{q_A} \right] & q_1 < q_A < q_2 \\
 l_e &= l_{e1} + l_{e2} = (L - G) \left[1 - \frac{q_1}{q_A} \right] + (L - B) \left[1 - \frac{q_2}{q_A} \right] & q_2 < q_A
 \end{aligned} \tag{10}$$

The values of l_e will vary from year to year, but in the long term, will tend towards its expected value which can be used as an indicator of probable erosion. This can be determined by:

$$\langle l_e \rangle = \int_0^{\infty} l_e f(l_e) dl_e \tag{11}$$

where: $\langle l_e \rangle$ = expected value of l_e
 $f(l_e)$ = probability density function for l_e

Since l_{e1} and l_{e2} are single-valued functions of q_A and since dl_{e1}/dq_A and dl_{e2}/dq_A are positive for all q_A , the fundamental theorem of probability states:

$$\begin{aligned} f(l_{e1}) dl_{e1} &= f(q_A) dq_A = dF(q_A) \\ f(l_{e2}) dl_{e2} &= f(q_A) dq_A = dF(q_A) \end{aligned} \quad (12)$$

$f(q_A)$ = probability density function for q_A

$F(q_A)$ = cumulative density function for q_A

By substituting (10) and (12) into (11):

$$\begin{aligned} \langle l_e \rangle &= \int_{q_1}^{\infty} (L - G) \left[1 - \frac{q_1}{q_A} \right] f(q_A) dq_A + \int_{q_2}^{\infty} (L - B) \cdot \\ &\quad \left[1 - \frac{q_1}{q_A} \right] f(q_A) dq_A = (L - G) F(q_1) - q_1 \int_{q_1}^{\infty} \frac{dF(q_A)}{q_A} \\ &\quad + (L - B) F(q_2) - q_2 \int_{q_2}^{\infty} \frac{dF(q_A)}{q_A} \end{aligned} \quad (13)$$

Equation (13) relates expected amount of erosion next to the backfill mound to the variety of parameters listed in the introduction to this chapter. In spite of the symbolic complexity it can be easily evaluated numerically and provides a basis for comparison of alternative erosion control measures.

6.4 Expected Annual Cost per Foot

The question of physical feasibility is not appropriate for the designs presented in the exhibit. A continuous gravel cap, main-

tained to the natural grade would be far more stable than the natural soil cover and therefore would be virtually guaranteed to resist erosion. The problem is really one of economics, that is, which combination of control measures will give the least expensive design.

The expected annual cost during the critical period prior to revegetation is:

$$C_A = \frac{C_B B}{L} + f \frac{C_G G}{L} + \frac{C_R < 1_e >}{L} \quad (14)$$

where: C_A = total expected annual cost/ft

C_B = mound break maintenance cost/ft

C_G = gravel protection construction cost/ft

f = capital recovery factor

C_R = erosion repair cost/ft

L = break spacing

Calculations showed the best choice of L and G were sensitive only to the relative orders of magnitude of C_B , C_G , and C_R . Therefore, the following approximate values were used for this example.

6.4.1 Mound Break Maintenance Cost

It was assumed a winter maintenance program would be necessary to maintain the mound breaks at ground level. Assuming a one foot section of a berm break has a width of 9 feet and subsides 1.0 feet, C_B equals 1/3 the cost of one yard of gravel in place. Since

the maintenance cost will be incremental, C_B need not include a base cost. C_B was taken as \$30/ft/yr, although it is recognized that C_B may often be zero.

6.4.2 Gravel Berm Construction Cost

C_G was estimated at \$10/ft. It was assumed this could be amortized over a four year period, the length of the period until vegetation is re-established.

6.4.3 Erosion Repair Cost

The daily cost of a major repair program, conducted in the summer, was estimated at \$25,000 by Arctic Gas. It is estimated that the crew could backfill about 100 ft/day of seriously eroded ditch. Therefore, C_R was taken as \$250/ft.

6.5 Selection of the Optimum Design

The flood frequency calculation, described in Section 6.2, was repeated for several hypothetical catchment areas in the same vicinity, but smaller in size, than the one presented in Figure 10. The results were then applied to equation (12) and (13) and the minimum cost solution was located by trial and error. It was found that an optimum break spacing did exist but that when gravel backfill was required, it was usually more economical to use gravel for the entire section under consideration and increase the mound break spacing.

A sensitivity study was not conducted but all parameters used in the various equations were systematically varied to estimate their

significance. It appears that ditch slope, length of catchment slope and nature of the backfill material are of first order importance. Holding all other variables constant, the optimum break spacing was determined for a range of these parameters. The results are presented in Figure 12.

6.6 Conclusion

Although quantifying erosion involves many parameters, it is possible to build a model by hydrologic and hydraulic transformation of rainfall statistics to estimate the best combination of erosion protection measures given the characteristics of a section of the right-of-way. The results seem sensitive only to a small number of variables, which suggest simple design curves, such as those presented in Figure 12, can be developed. Therefore, it appears possible to support the erosion and control measures presented in Section 3 with a rational basis for design.

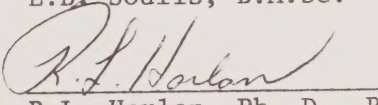
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Approved by:


R.L. Harlan, Ph. D., P. Geol.

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1. Typical Climatological Parameters Along Pipeline Route
2. Allowable Values for Selected Soil Types

TABLES

TABLE 1

TYPICAL CLIMATOLOGICAL PARAMETERS ALONG PIPELINE ROUTE *

Location	Annual Number of Thunderstorm Days (Days)	Winter Discharge Equivalent (Inch/Day)	Winter Discharge Equivalent (Inch/Day)
<u>LIST OF TABLES</u>			
Barrow	15.0	0.40	1.0
1. Typical Climatological Parameters Along Pipeline Route			3.0
2. Allowable Velocities for Selected Soil Types			7.0
Umanak	15.0	0.60	1.0
(Barrow Island)			

* U.S. Environmental Protection Board, 1974, Impact on Environmental Impact
Assessment of the Location of the Mackenzie Gas Pipeline from Alaska
to Quebec, August 1974, Geotechnical and Hydrological Studies -
the Impact of the Effects, January Report No. 1.

TABLE 1

TYPICAL CLIMATOLOGICAL PARAMETERS ALONG PIPELINE ROUTE *

Station	Annual Number of Independent Runoff Events	Storm Duration Exponent (/day) λ	Storm Intensity Exponent (days/in.) β
Fort Simpson	21.0	0.40	5.0
Norman Wells	21.5	0.40	5.0
Fort Good Hope	19.0	0.60	7.0
Tuktoyaktuk (Barter Island)	15.0	0.60	7.0

- * Environmental Protection Board, 1973, Towards an Environmental Impact Assessment of the Portion of the Mackenzie Gas Pipeline from Alaska to Alberta, Appendix IV, Geotechnical and Hydrological Studies - Off Right-of-Way Effects, Interim Report No. 3.

TABLE 2

ALLOWABLE VELOCITIES FOR SELECTED SOIL TYPES*

<u>Material</u>	<u>Manning "n"</u>	<u>Velocity (ft/sec) For Clear Water</u>
Fine Sand	.020	1.50
Silty Sand	.020	1.75
Fine Gravel	.020	2.50
Stiff Clay	.025	3.75
Coarse Gravel	.025	4.00
Well Graded Gravel		
Cobbles	.035	5.00
Shale, Land pan	.025	6.00

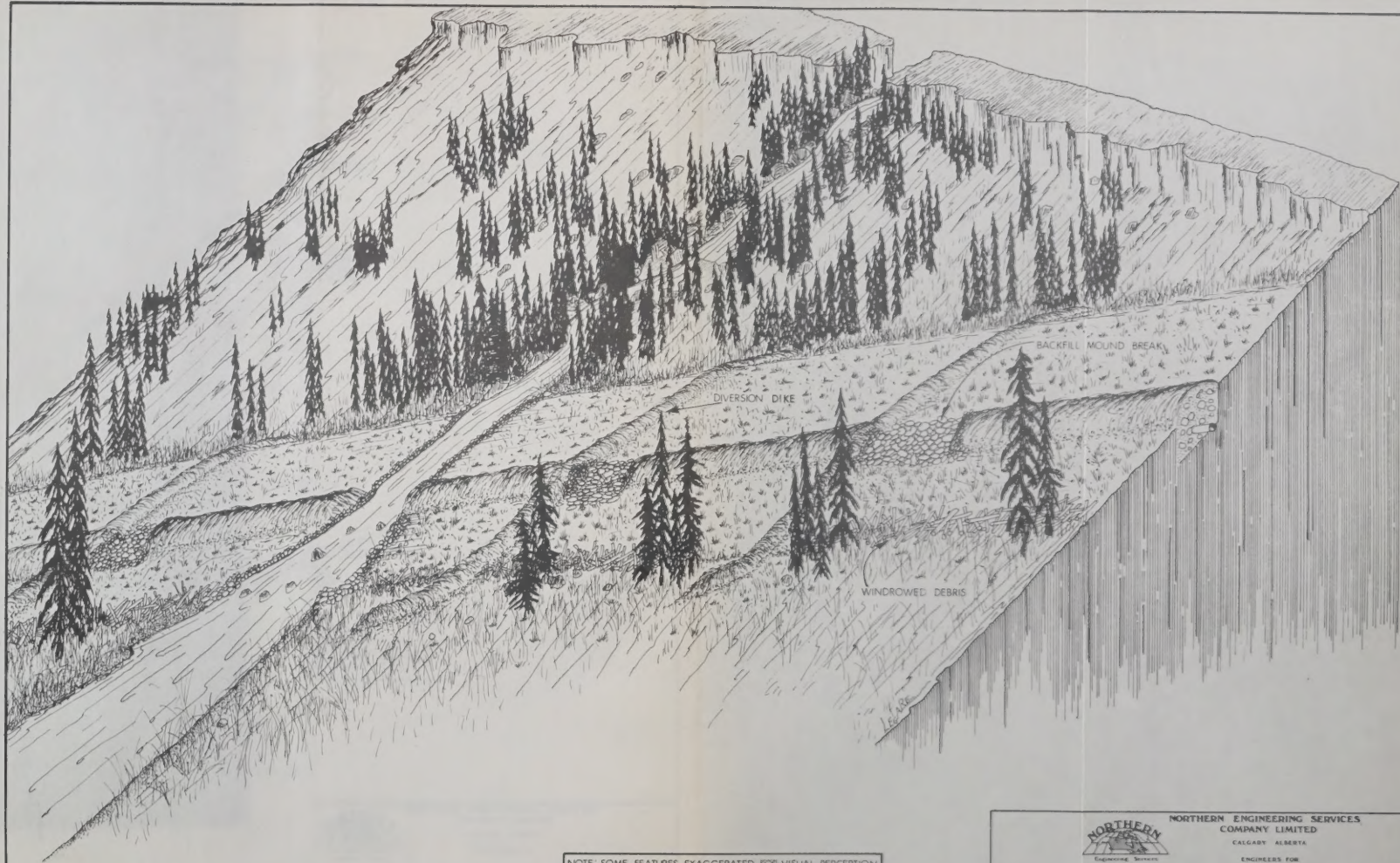
* American Iron and Steel Institute, 1971, Handbook of Steel Drainage and Highway Construction Products, The Lakeside Press.

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1. Example of Precision and Precision Control Measures on Pipeline Right-of-Way in Wilderness Regions
2. Precision and Precision Control Measures - Schematic Diagrams
3. Precision and Precision Control Measures - Software
4. Example of Precision and Precision Control Measures on Pipeline Right-of-Way
5. Example of Precision and Precision Control Measures Along Perennial Stream Banks
6. Pipeline Intersection ILLUSTRATIONS
7. Pipeline Intersection Area
8. Histogram of Pipeline Widths and Lengths - 1980-1985
9. Histogram of Pipeline Widths and Lengths - 1986-1990
10. Annual Wind Frequency for a Representative Watershed Area Located on the Pipeline
11. Precision Model
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- 2 Drainage and Erosion Control Measures - Schematic Diagrams
- 3 Drainage and Erosion Control Measures - Sections
- 4 Example of Drainage and Erosion Control Measures on Pipeline Right-of-Way
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- 6 Upslope Interception of Icing
- 7 Idealized Catchment Area
- 8 Histograms of Combined Rainfall and Snowmelt - Duration
- 9 Histograms of Combined Rainfall and Snowmelt - Intensity
- 10 Annual Flood Frequency for a Hypothetical Catchment Area Crossed by the Pipeline
- 11 Erosion Model
- 12 Example Design Curve for Mound Break Spacing Related to Backfill Material



NOTE: SOME FEATURES EXAGGERATED FOR VISUAL PERCEPTION

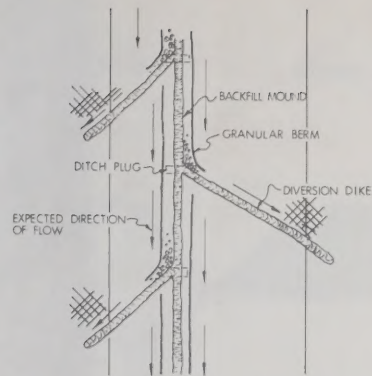


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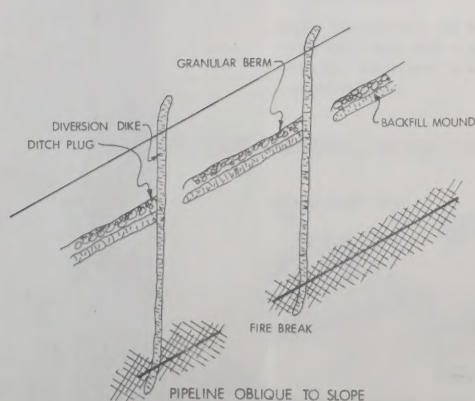
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EXAMPLE OF DRAINAGE & EROSION CONTROL MEASURES
ON PIPELINE R.O.W IN PERMAFROST REGIONS

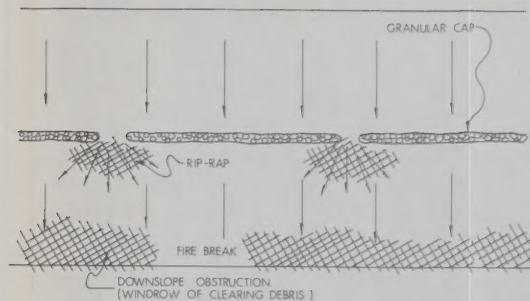
FIGURE 1



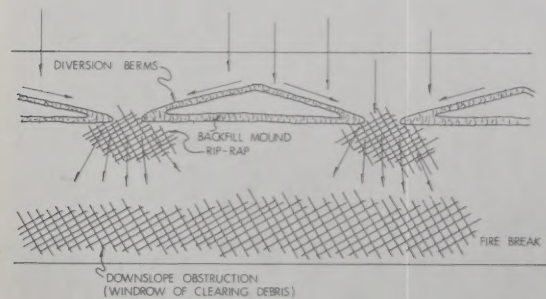
PIPELINE PARALLEL TO SLOPE



PIPELINE OBLIQUE TO SLOPE



PIPELINE PERPENDICULAR TO SLOPE
SUB-SURFACE FLOW PRESERVED



PIPELINE PERPENDICULAR TO SLOPE
PONDING CONTROL REQUIRED

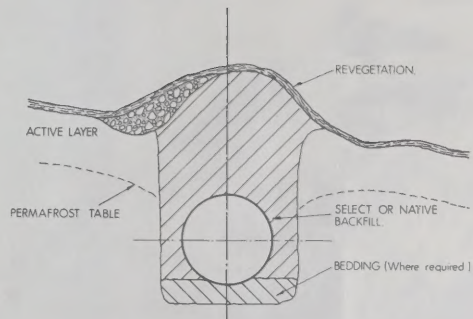


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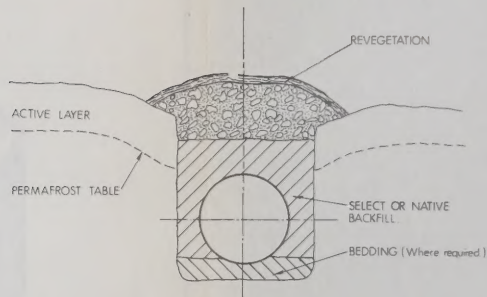
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DRAINAGE & EROSION CONTROL MEASURES
SCHEMATIC DIAGRAMS

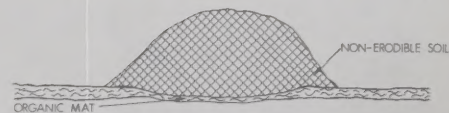
GRANULAR BERM



GRANULAR CAP



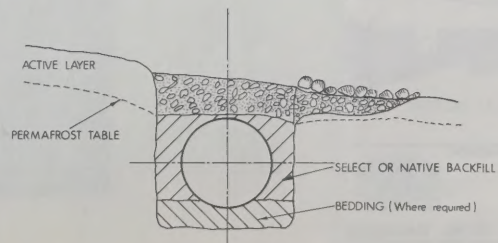
DIVERSION DIKE



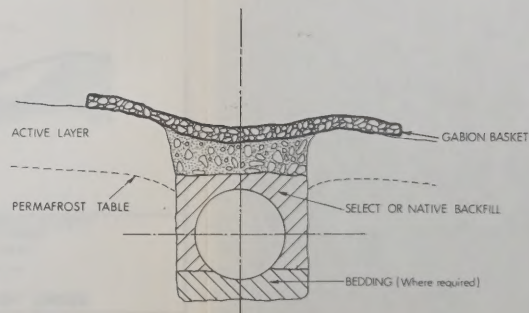
NOTES

1. SELECT BACKFILL IS SHOWN ONLY WHERE REQUIRED FOR DRAINAGE OR EROSION CONTROL. ADDITIONAL GRAVEL MAY BE USED FOR GEOTHERMAL, BUOYANCY, OR STRUCTURAL REASONS.
2. DITCH CONFIGURATIONS ARE SHOWN FOR ICE-RICH PERMAFROST SOILS PRIOR TO STARTUP. THE CONTROL MEASURES SHOWN APPLY TO ALL REGIONS WHERE REQUIRED.

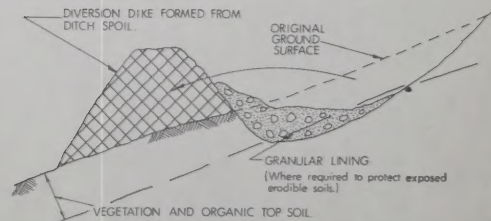
SECTION AT BACKFILL MOUND BREAK



GABION PROTECTION



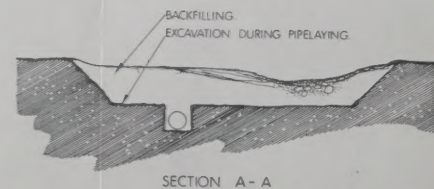
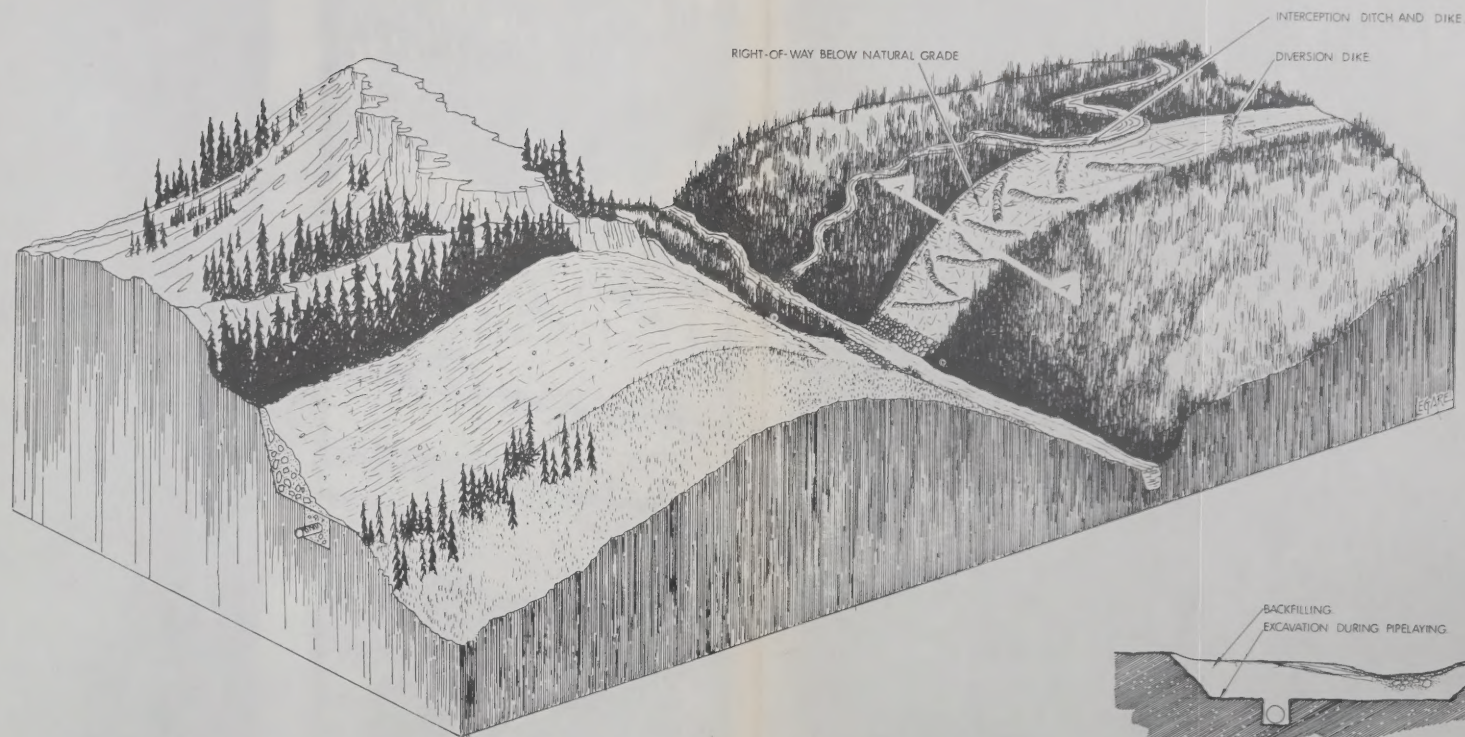
DIVERSION DIKE AND DRAINAGE DITCH



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DRAINAGE & EROSION CONTROL MEASURES
SECTIONS



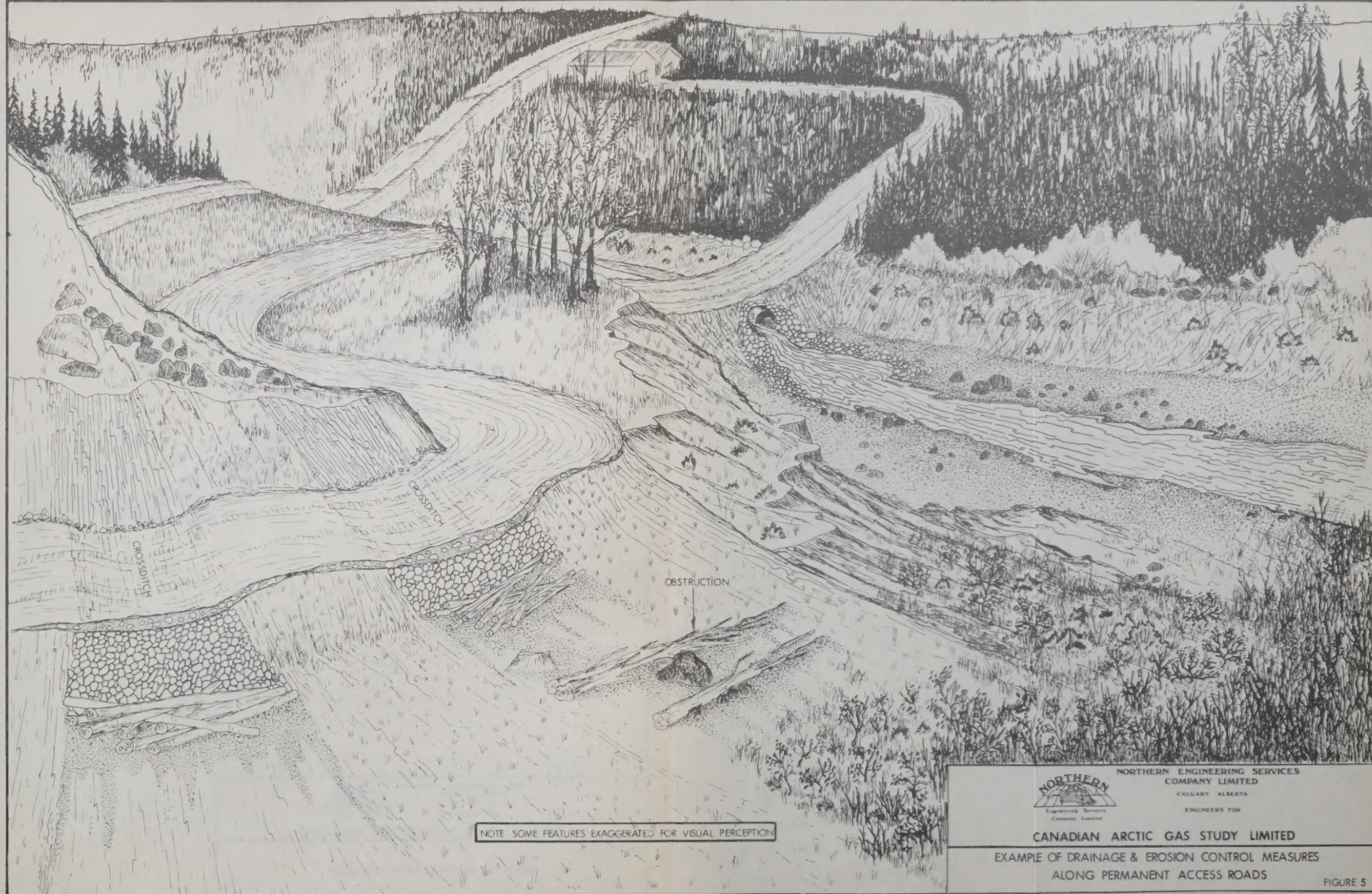
NOTE SOME FEATURES EXAGGERATED FOR VISUAL PERCEPTION



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EXAMPLE OF DRAINAGE & EROSION CONTROL
MEASURES ON PIPELINE R.O.W

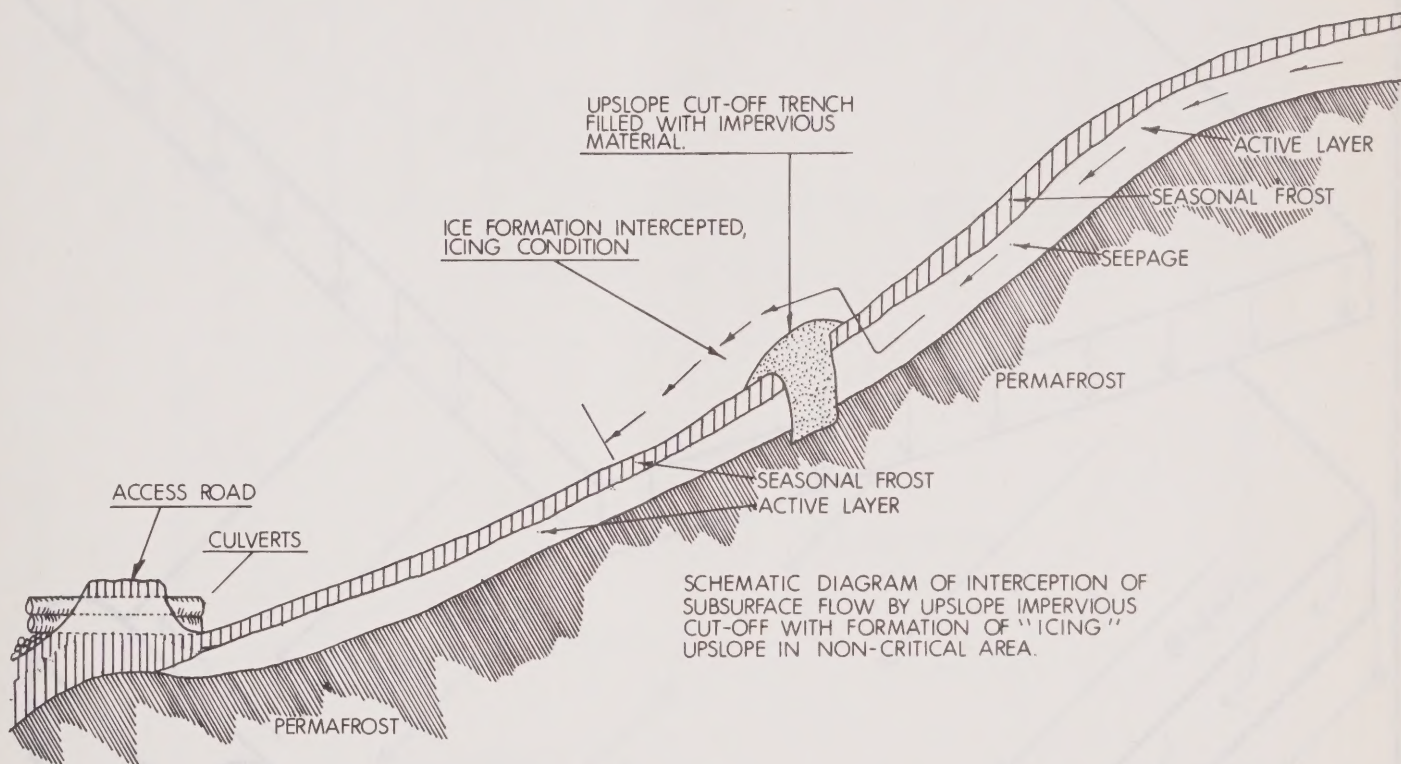


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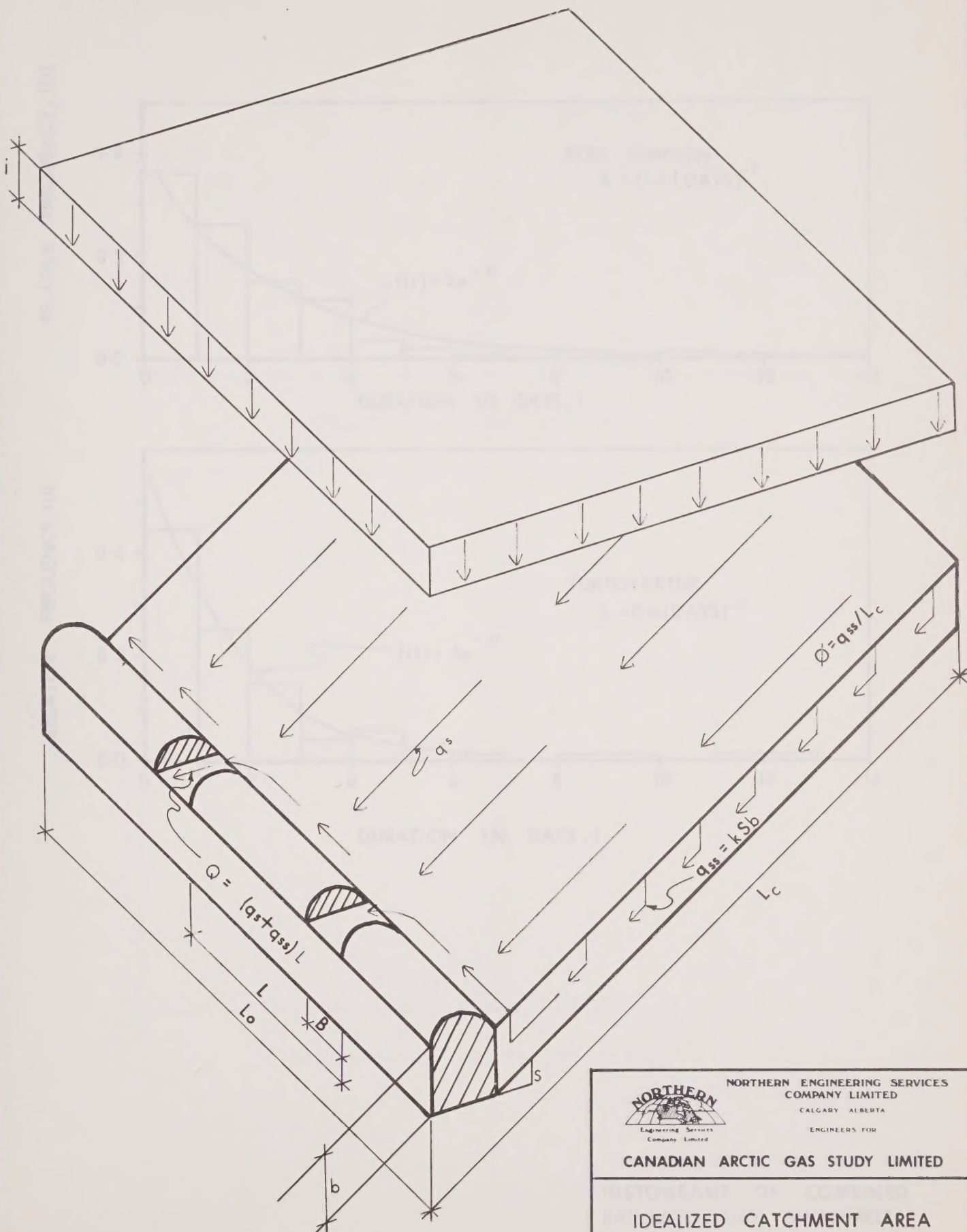
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EXAMPLE OF DRAINAGE & EROSION CONTROL MEASURES
ALONG PERMANENT ACCESS ROADS



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UPSLOPE INTERCEPTION OF ICING



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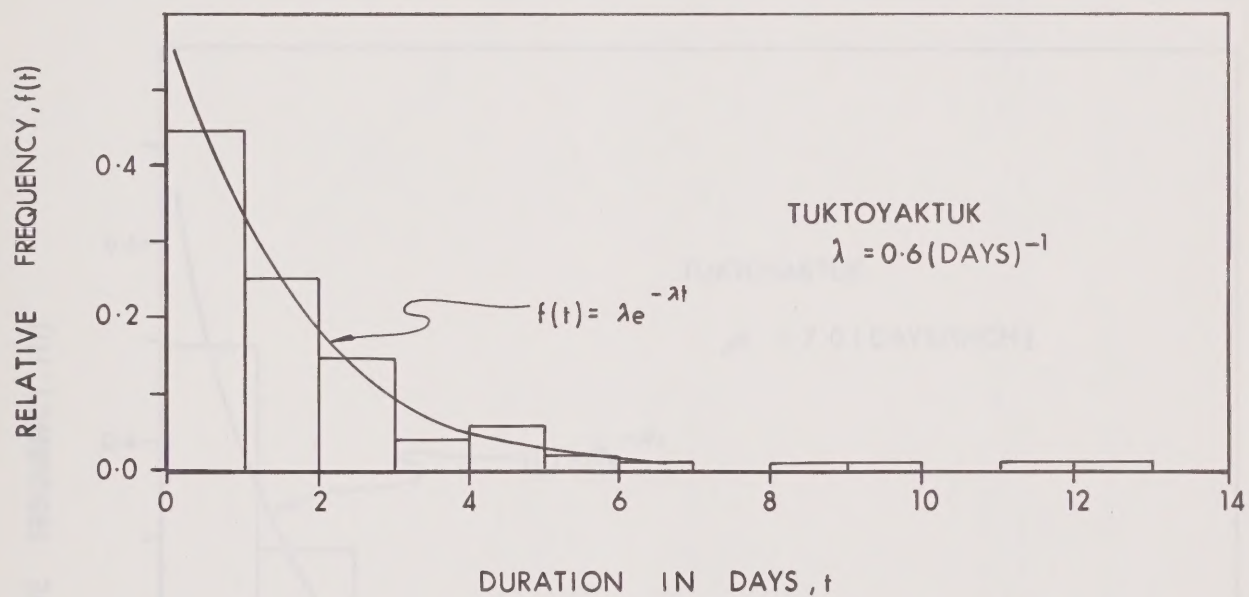
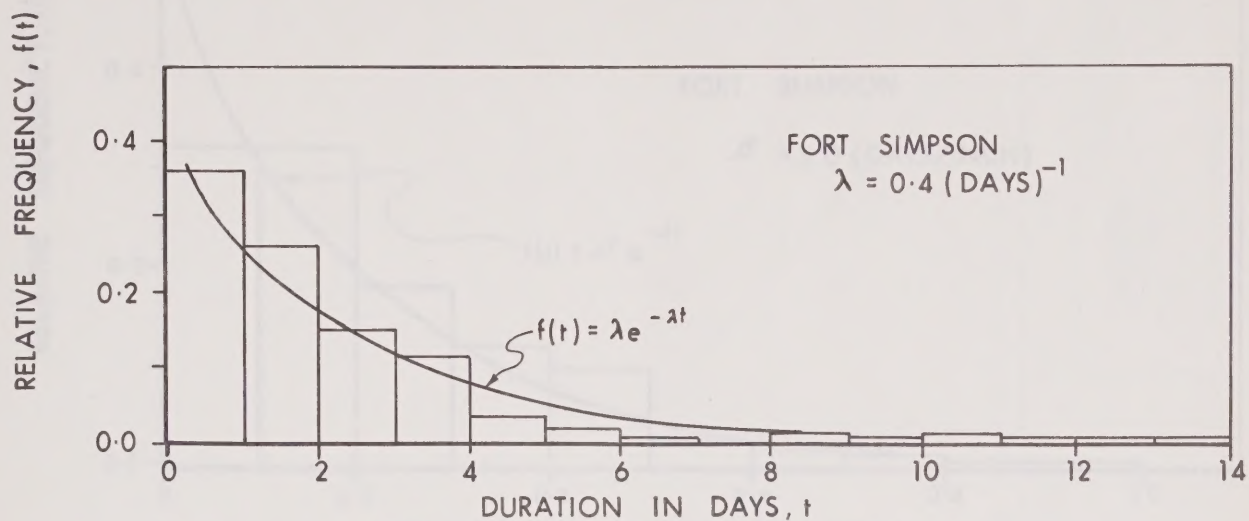
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IDEALIZED CATCHMENT AREA

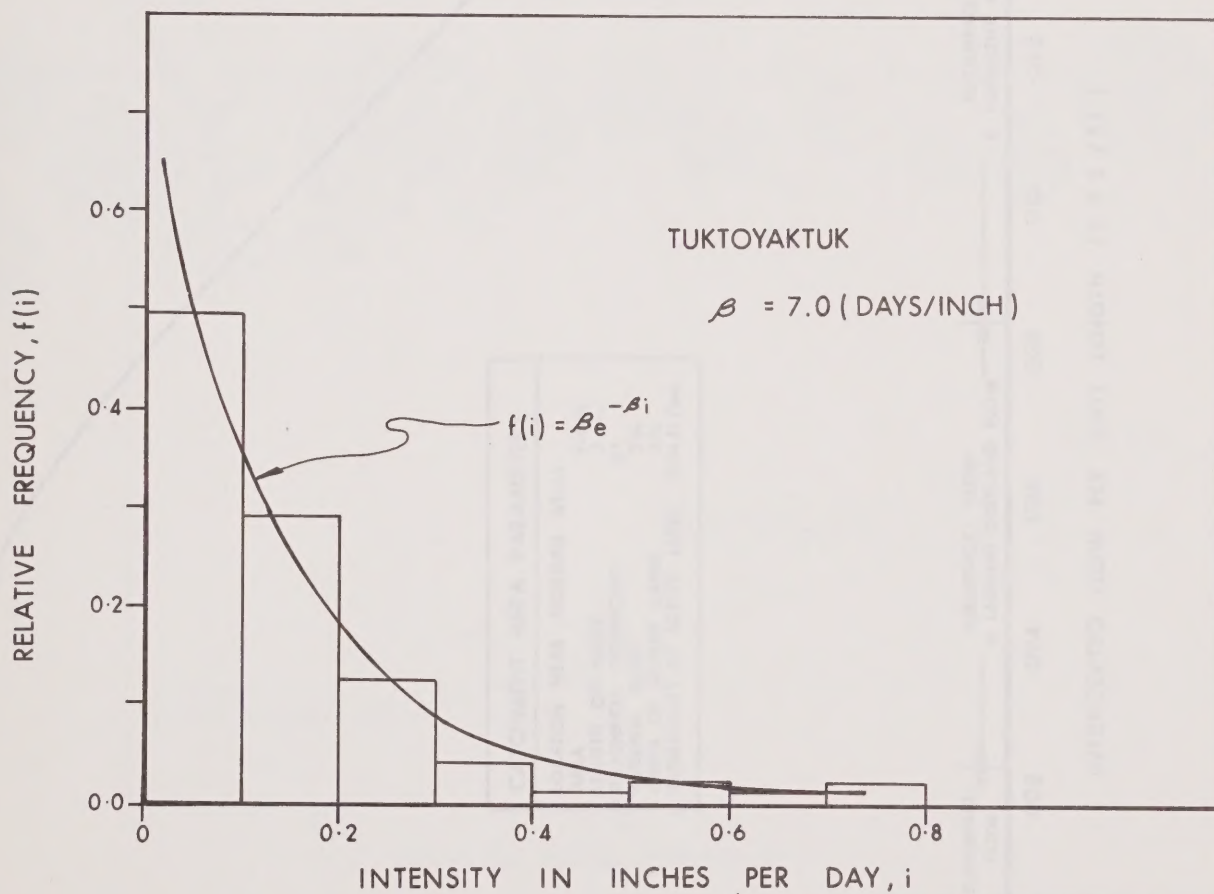
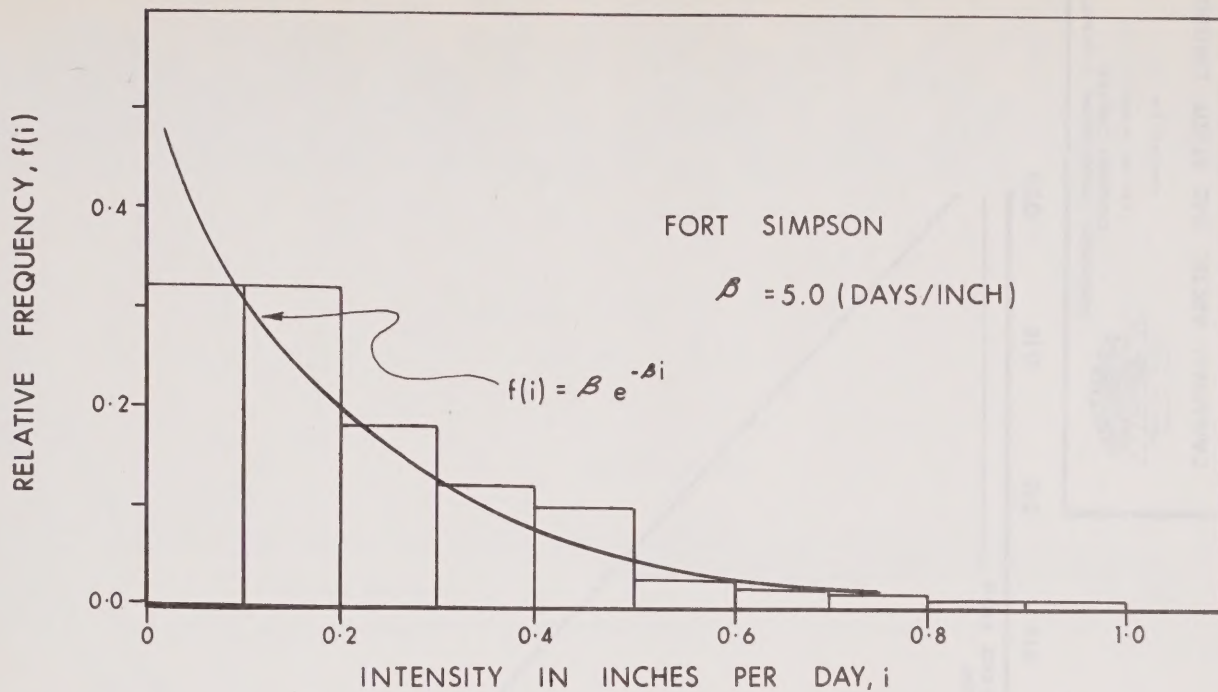
FIGURE 7



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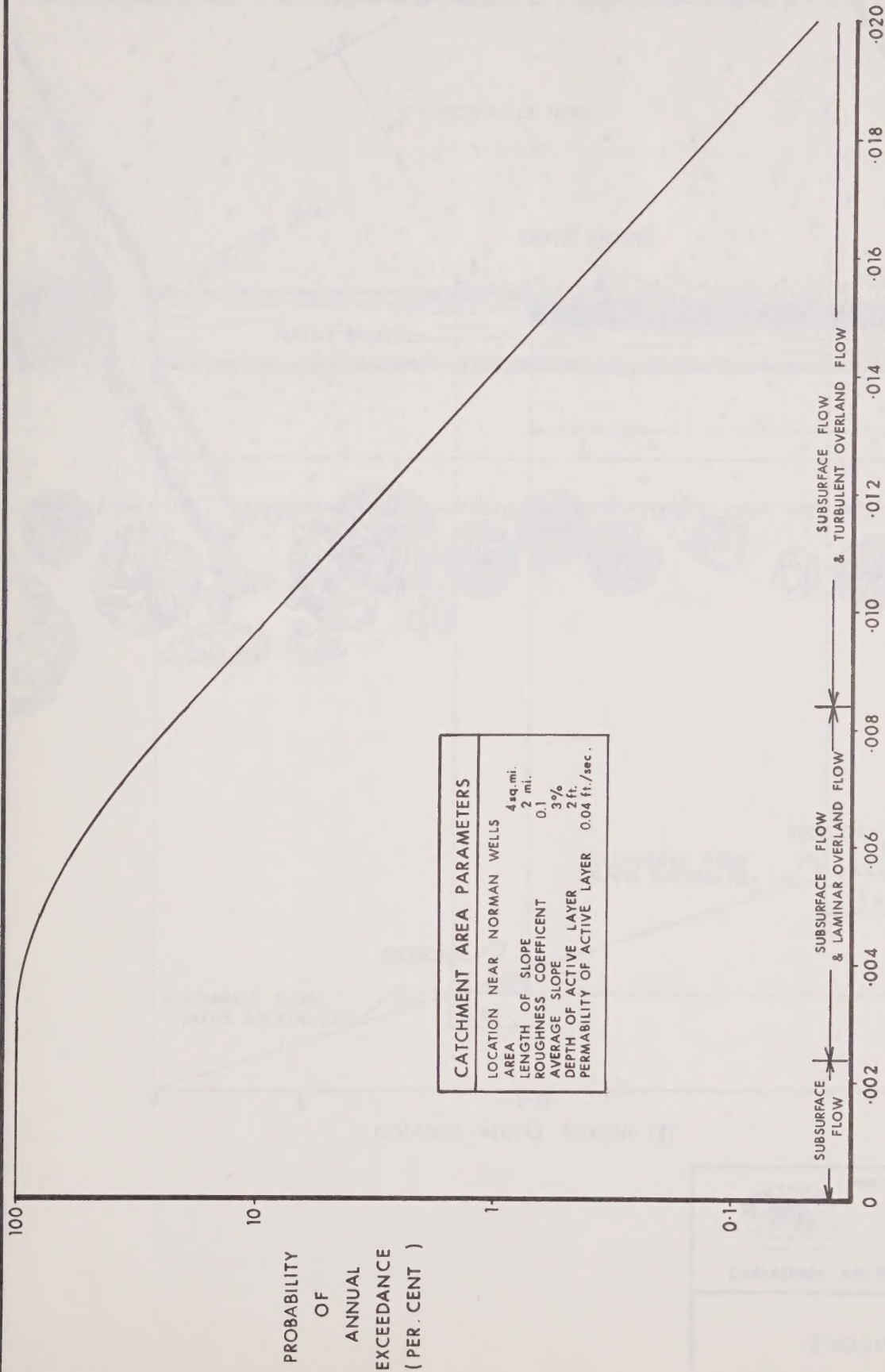
HISTOGRAMS OF COMBINED
 RAINFALL AND SNOWMELT
 DURATION.



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HISTOGRAMS OF COMBINED
RAINFALL AND SNOWMELT
INTENSITY

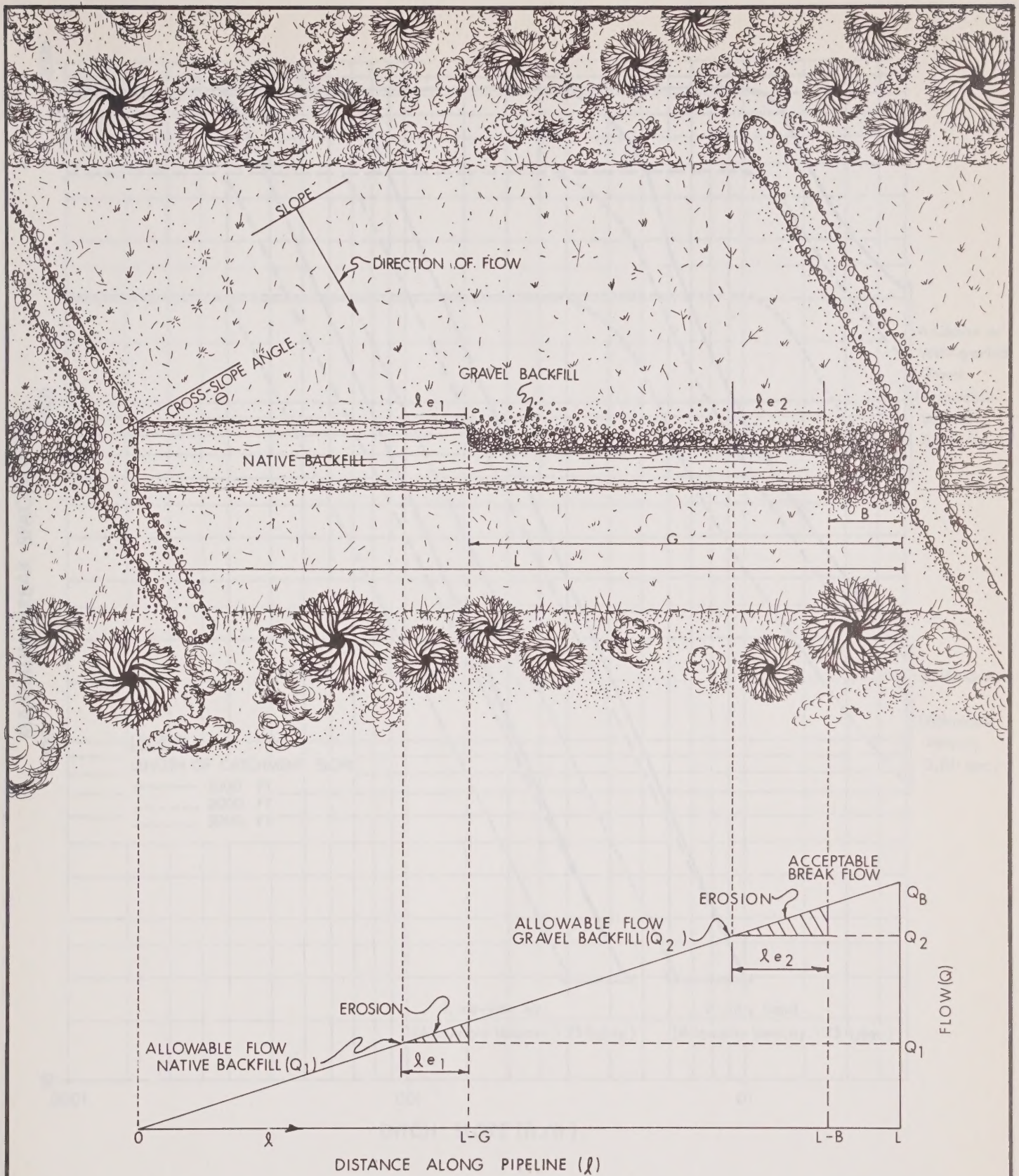


CATCHMENT AREA PARAMETERS	
LOCATION NEAR NORMAN WELLS	4 sq. mi.
AREA	2 mi.
LENGTH OF SLOPE	0.1
ROUGHNESS COEFFICIENT	3%
AVERAGE SLOPE	2 ft.
DEPTH OF ACTIVE LAYER	0.04 ft./sec.
PERMEABILITY OF ACTIVE LAYER	

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ANNUAL FLOOD FREQUENCY
 FOR A HYPOTHETICAL CATCHMENT
 AREA CROSSED BY THE PIPELINE



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EROSION MODEL

FIGURE 11

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APPENDIX 1 - Application to BAME

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APPENDIX 1 - Application to DIAND

Section 8b.1.3.8.1 - Drainage and Erosion Control

Section 8b.1.3.8.4.1 - Erosion Control Measures

The purpose of this section is to provide information on the erosion control measures that will be used on the project.

The erosion control measures that will be used on the project are:

- Vegetation at the top of the slope.
- Slope stabilization by the use of geotextiles and geogrids.
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The erosion control measures that will be used on the project are:

8b.1.3.8.1 - DRAINAGE AND EROSION CONTROL

Erosion as discussed in this section refers only to accelerated erosion caused by man-made removal or disturbance of surface vegetation and soil. Once initiated, the rills and gullies that rapidly form can be very difficult to control. Such erosion in the vicinity of the pipeline right-of-way would be undesirable, and would be detrimental to the revegetation and restoration measures. The serious effects of accelerated erosion can be prevented by controlling surface run-off and ground water flow across the areas disturbed by the construction and operation of the pipeline.

The principle factors governing the rate and severity of erosion due to the action of water are:

- Vegetation at ground surface
- Upslope topography, and in particular the steepness and length of slope,
- Location of the right-of-way relative to the watershed,
- Rainfall intensity and duration,
- Infiltration rate of the soil,
- Sediment load of surface runoff,
- Texture, structure and chemistry of the soil in the top six inches below ground surface.

Surface erosion during spring run-off will be minimal as the ground is usually frozen and the bonding at ground surface prevents soil particle dislodgement. Maximum erosion will occur during the summer storm run-off. The potential for erosion will be greatest where the soil in the backfill mound and in areas of surface disturbance on the right-of-way is exposed to flowing water.

Drainage and erosion control measures will be incorporated into pipeline construction to minimize changes to the existing hydrological regime and to prevent detrimental erosion. The hydrological regime in this context includes the movement of both surface and sub-surface water across the right-of-way and into stable drainage courses on the downslope side of the pipeline. The drainage and erosion control measures have been designed to localize any minor disturbance that results from pipeline construction and operation to the immediate vicinity of the pipeline right-of-way.

Erosion will be controlled by minimizing interference with natural drainage patterns, until the protection of the revegetation measures become effective. Revegetation will provide stabilized cover to the ground surface.

The presence of the pipe in the ditch and bulking of excavated material result in excess spoil remaining after the ditch has been backfilled. This excess material will be mounded over the ditch and provision will be made to maintain drainage across the right-of-way and to discourage the development of gullies from concentrated flows.

Construction methods have been designed to limit thermal degradation and consequent settlement of high ice content permafrost soils by minimizing disturbance to the ground surface cover. Settlement does not follow the melting of low ice content soils. Where degradation of ice-rich permafrost soils may occur, water ponded in the affected area will be drained, where possible, to reduce thawing and subsequent settlement of ground surface.

Thermal degradation can be started by either man-made or natural (fire, landslides) disturbance to the ground surface cover. Removal of the surficial vegetal cover causes thermal degradation; however, significant thermal degradation can be caused without complete removal where the organic material is thin. Permafrost degradation is undesirable with respect to pipeline activities, as once initiated in ice-rich areas the affected area may continue to expand and deepen in the form of a thaw-pond. Thermokarst topography in ice-rich areas is caused by thermal degradation.

The detrimental effects of fire on permafrost are determined by the intensity of the fire and the resulting destruction of the surficial layer of organic materials. Where the surface is not seriously damaged during a fire, the active layer may experience only a temporary thickening and will return to its original depth within a few years as the vegetation becomes re-established. The effects are more severe when fires of greater intensity burn off the surficial vegetal layer, expose mineral soil, and blacken the surface. In high ice content permafrost, water erosion, subsidence of ground surface, and surficial instability of relatively gentle slopes can occur before thermal equilibrium is attained by the regrowth of vegetation.

The potential for slope movement due to forest fire on and beyond the right-of-way that could expose the pipe will be considered during design. At most locations where such a potential exists, slope stabilization measures will be applied after a fire where there is an indication of incipient slope failure.

Drainage controls related to icings have been considered in the Applicant's design. Icings present a hazard which can render a road impassable. They occur where springs or groundwater flowing under confined pressure emerge during the winter through cracks and fissures in the frozen ground surface in both permafrost and non-permafrost terrain. The water subsequently spreads and freezes in successive layers of ice covering the ground surface. The icings continue to increase in thickness and extend throughout the winter as long as the water flows. It is possible that there will be locations along the route where changes to the ground thermal regime will interfere with ground water flows and cause icings. Although there will be no serious detrimental effects to the pipeline itself from icings, their effect on maintenance and emergency access has been considered.

Along most of the pipeline route the maximum slope occurs along the right-of-way is less than about three degrees. Consequently, in those flat or gently sloping areas, runoff collection and control will be the primary drainage concern. In the vicinity of backfills, at low points where defined drainage channels are required, which the road is available, at these low points the backfill will be contained such a permanent drainage being.

On the limited sections of the route in areas where there are slopes steeper than about three degrees, although conventional drainage will generally be followed, some additional features will be required to prevent erosion due to higher water volumes. Surface and subsurface runoff, except flows in well-defined drainage channels, will be directed across the backfill mound through gravel protected breaks and discharged as concentrated flows into the established area on the downslope side. Gravel protection will be provided across eroders on the upslope side of the backfill mound. Where necessary, low diversion ditches and surface drains will be used to intercept and divert the runoff. On relatively steep slopes to up, amounts of rock, brush, shrubs, or stumps may be used on the ground surface across the drainage side of the mound breaks to discourage the development of gullies. From embankment foot. Flow along and through the ditch will be prevented by vegetation, plastic placed on the downslope side of the mound breaks. These proposed features are illustrated schematically in Figure 1 to 3.

Where the positive details of mounds or slopes steeper than about three degrees in which gravel protected areas and channels are such that right-of-way defined as drainage main lead to erosion or instability, selected water backfill will be used. Where possible, in the case of mounds where the use of deep drainage will be avoided and grading of water will be prevented.

The proposed maximum road on slopes steeper than about three degrees is more specialized internal and surface conventional features. They will be similar to those described previously for the more gentle permanent slopes, except that gravel will only be required to protect mound breaks on steep slopes in suitable soil and necessary steps will be required left permanently fixed on

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4. CONTROL MEASURES

4.1 Erosion Control Measures

It is necessary to prevent erosion in the vicinity of the ditch and right-of-way both to maintain the integrity of the pipeline and to minimize disturbance to the ground surface in response to environmental concerns.

Erosion will be prevented by a combination of construction techniques, simple but effective measures where necessary along the route to control surface and subsurface drainage, planned revegetation techniques and a planned program of regular inspection and maintenance after construction.

The present section deals with the drainage measures and the techniques of revegetation. Construction techniques and inspection and maintenance aspects are covered elsewhere in this Application.

a) PIPELINE RIGHT-OF-WAY

The backfill will be mounded over the ditch so that after settlement has occurred there will be a low mound rather than a gully over the ditch line. The program of inspection and maintenance will ensure that fill will be placed where gullies locally form over the pipe and there is likely to be significant erosion.

Along most of the pipeline route the maximum slope across or along the right-of-way is less than about three degrees. Consequently, in these flat to gently sloping areas, run-off velocities are sufficiently low that drainage control measures will be the provision of breaks in the backfill mound at low points, where distinct drainage courses are crossed. Where the soil is erodible, at these low points, the breaks will be protected with a non-erodible granular lining.

On the limited sections of the route in permafrost areas where there are slopes steeper than about three degrees, although conventional practice will generally be followed, some additional features will be required to prevent erosion due to higher water velocities. Surface and subsurface run-off, except flows in well-defined drainage courses, will be diverted across the backfill mound through gravel protected breaks and discharged in unconcentrated flows into the undisturbed area on the downslope side. Granular protection will be provided where necessary on the upslope side of the backfill mound. Where necessary, low diversion dikes and shallow ditches will be used to intercept and divert the run-off. On relatively steep slopes riprap, consisting of trees, brush, shrubs, or stones, may be laid on the ground surface across the discharge side of the mound breaks, to discourage the development of gulying from concentrated flows. Flow along and through the ditch will be prevented by impervious plugs placed on the downslope side of the mound breaks. These proposed measures are illustrated schematically in Figures 1 to 3.

Where the pipeline descends or ascends a slope steeper than about three degrees in ice-rich permafrost areas and conditions are such that backfill settlement on thawing could lead to erosion or instability, selected stable backfill will be used. Where possible, in ice-rich permafrost areas, the use of deep drainage will be avoided and ponding of water will be prevented.

The control measures used on slopes steeper than about three degrees in non-permafrost terrain will follow conventional practice. They will be similar to those described previously for the more stable permafrost terrain, except that gravel will only be required to protect mound breaks on steep slopes in erodible soil and impervious plugs will be required less frequently than in

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permafrost terrain.

The various types of drainage and erosion control measures are described in the following paragraphs.

i) Revegetation

Construction activities associated with the installation of the pipeline and ancillary facilities will be carefully controlled so that there is minimum disturbance to the plant cover, except where excavation is required such as the pipeline ditch. The revegetation measures provide long-term soil stabilization. The drainage and erosion control measures described in parts ii) to x) immediately following provide the short-term control of surface and sub-surface water during the period that the new vegetation becomes established.

The primary means for re-establishing plant cover on exposed soil will be the application of seed and fertilizer. Other methods to be used on less extensive segments of the route include the stripping and replacing of the organic mat in many tundra areas, hand planting of shrub cuttings on sideslopes and the laying of preseeded soil binding mats.

ii) Backfill Mound Breaks

Along the pipeline route, breaks will be left in the backfill mound to permit surface drainage to cross the pipe ditch and to prevent ponding or flow parallel to the ditch backfill on its upslope side. The breaks will be 5 to 12 feet wide. The surface of the break and adjacent slopes will be covered with a protective layer of non-erodible soil where the ditch backfill could be eroded by the concentrated flow. In these areas riprap in the form of logs, shrubs or coarse cobbles and stones may be placed across the cleared right-of-way on the downslope side of the berm breaks to discourage the water from flowing in concentrated channels before it reaches the undisturbed area.

The spacing of breaks will depend on upslope run-off characteristics, degree and length of slope and defined drainage channels crossing the line.

Average spacing of breaks as determined by an air photo study has been shown on the alignment sheets. The actual location of each break will be determined by ground survey and marked before construction commences. This location work will be carried out during early summer when the drainage courses are flowing and are not obliterated by snow.

iii) Ditch Plugs

Where erosion of the backfill from water flowing through the ditch is possible, impervious ditch plugs will be placed across the ditch. The plugs will be located on the downslope side of breaks in the backfill mound and elsewhere as required to prevent water flowing through the ditch. The plugs will be constructed of impervious material such as fine-grained silty clays, or bentonite-enriched backfill soil placed either in sacks or between forms. The plugs will be keyed into the walls of the pipe ditch to prevent significant seepage around the ends of the plug.

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iv) Diversion Dikes

Diversion dikes will be used where it is necessary to interrupt and direct large volume run-off across the right-of-way.

In ice-rich areas subject to settlement following thermal degradation, diversion dikes will be constructed of sand bags or of pit run granular soils placed either on top of the vegetative cover at ground surface or in a shallow trench where subsurface flow must be intercepted.

In stable permafrost and in non-permafrost areas the dikes will be constructed of soil and vegetation debris excavated from the drainage ditches.

The dikes will be oriented obliquely to the pipeline on either the upslope side or on both sides of the right-of-way depending on the orientation of the pipeline to the slope. The dikes will be extended to the uncleared undisturbed ground. Actual spacing, orientation and location of the diversion dikes will be determined in the field prior to or during construction.

v) Drainage Ditches

In non-permafrost terrain and permafrost terrain which is thaw stable, drainage ditches excavated as adjuncts to the diversion dikes where large flows, which could cause widespread flooding upslope of the backfill mound, are anticipated. In erodible soils and where large flows are anticipated, the ditches will be lined with non-erodible granular soil. In general, ditches will not be used in permafrost terrain where thermal degradation could follow surface disturbance. An exception would be where a ditch is required to remove water ponding in areas of thermokarst subsidence due to permafrost regression.

Interceptor ditches may be used on the upslope side of any area susceptible to erosion as an alternative to protecting the slopes with flow obstructions. (See vi below). Interceptor ditches will have greatest application along the top of excavated slopes, to prevent erosion of the exposed face. They will also be located on the upslope edge of the pipeline right-of-way in areas where large flows must be diverted away from the buried pipe.

vi) Flow Obstructions

The erosive capacity of flowing water can be reduced by placing obstructions in its path, which have the effect of breaking up concentrated flows, reducing the flow velocity, and causing sedimentation. Windrowed trees and brush from the clearing operations will be used as obstructions at the base of steep excavated slopes. In areas of higher erosion risk, the clearing debris will also be placed on the face of the excavated slope perpendicular to the anticipated flow direction.

vii) Granular Protection of Backfill Mound

In areas where erosion could occur along depressed channels parallel to the backfill mound, the upslope face of the mound will be protected with a layer of non-erodible granular soil. The granular soil will protect the backfill mound and the ground surface on the upslope side.

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viii) *Selected Backfill*

When the pipeline descends and ascends slopes where conditions are such that use of native backfill might lead to erosion or to backfill instability, a selected backfill of stable granular material will be employed. Such conditions generally occur only in permafrost areas on ice-rich slopes steeper than three degrees, where there is a significant depth of thaw prior to chilled pipeline operation.

ix) *River and Stream Training and Protection*

River and stream training will be provided at crossings where the banks, after backfilling, could be eroded by the flowing water. Erosion under these conditions could result in failure of the banks and exposure of the pipe. The protective works will consist of armouring the river bed and banks with rock or boulder riprap or gabions at the site of the crossing. River training works may also be required upstream depending upon the streamflow characteristics.

x) *Contingency Measures*

The drainage and erosion control measures specified have been based on the assumption that surface disturbance will be minimized to within acceptable limits during all phases of construction from the start of right-of-way preparation, to the completion of pipe installation. Contingency measures must be considered to remedy surface damage on the pipeline right-of-way that can occur in spite of strict control of construction activities. These measures, most of which are described previously, will include the following:

- revegetation
- insulation to arrest the degradation of permafrost
- riprap to protect erodible surfaces
- diversion dikes
- drainage ditches

b) ACCESS ROADS

Many miles of roads have been constructed successfully to date by the Federal Government and by industry in permafrost areas. The design and construction techniques are well known and generally require some modification from those in non-permafrost areas.

In permafrost areas, fill depths are often greater and cuts are minimized in ice-rich areas as far as possible. The drainage and erosion measures also require some modifications from those used further south.

Road locations adjacent to streams will in general be avoided. Where this is not possible, a buffer zone of undisturbed vegetation will be left between the road and stream. The surface of the road fill located near streams will be protected to prevent movement of soils into the streams. Deep cuts and fills in ice-rich areas will also be avoided. Where possible, all excavated back slopes will be protected against erosion.

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All major drainage courses will be crossed by bridges or culverts. The practice in non-permafrost areas of intercepting drainage, and channelling it in concentrated flows through culverts at maximum spacings will be modified in permafrost areas by providing more culverts at closer spacing. Where it is necessary to reduce the flow velocity due to environmental concerns such as the effect on fish migration, additional or larger bottomless type culverts will be provided.

Where the natural drainage is transverse to the road, the upslope side of the embankment will be protected from the erosive action of flow parallel to the road by a layer of coarse granular soil. Water courses upstream of culverts will be maintained free of obstructions. Downstream from culverts on cross-slopes of three degrees and greater, diffusers consisting of logs, clearing debris, rock or coarse pit-run gravel may be provided to the edge of the cleared right-of-way. Where the road is oriented to within 10 degrees of the dip of the natural ground slope, culverts may not be required. In this orientation, diversion dikes similar to those proposed for the pipeline right-of-way under similar slope conditions will be used to divert excess water outside of the cleared right-of-way.

In order to reduce the possibility of a washout during periods of peak flow, compacted granular backfill will be placed around and below culverts. The mouths of culverts will be provided with riprap aprons, and with down spouts in areas of unstable soils.

Cross ditching through the surface of the road will be acceptable as an alternative to culverts, in areas where the road crosses numerous poorly defined drainage courses. At locations where cross ditching is used, the upper foot of the road surface for a distance of 25 feet on both sides of the ditch will be constructed of coarse to medium sized gravel to prevent erosion. Cross ditch spacing will depend on the cross slope gradient and on the road surface material. Spacing will generally range between 150 feet and 75 feet.

In permafrost areas where the underlying soils are susceptible to thaw settlement, the use of excavated side ditches will be avoided where possible, and the technique of forming wide, shallow ditches by carefully controlled compaction of the surface after removal of most of the snow will be employed. Ditch blocks will be used where necessary to reduce the flow velocity.

c) SNOW ROADS

The use of snow roads will be limited to the period when an adequate wearing surface can be constructed of compacted snow or of ice. Clearing for winter roads will be restricted to the removal of trees and larger shrubs, and will result in minimum disturbance to the surface peat layer. The existing surface vegetative cover will provide erosion protection.

In general, no drainage and erosion measures will be required. If fill is placed which could impede drainage during spring run-off either culverts will be installed or the fill will be removed prior to the run-off period. If thaw settlement is anticipated, diversion dikes will be constructed to intercept the resulting flows and direct them into the virgin ground at the edge of the cleared area.

d) ICING CONTROL

The problems of icings in connection with northern roads is well known. In locations where icing

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occurs, the preferred solution will be to force the icings to form upslope and away from the road surface by either diverting the water at its source, or by locating the aquifer and inducing the groundwater to surface and form the icing further upstream. Adequate drainage facilities will be provided to allow the melt water from icings to dissipate in spring without causing erosion.

To provide adequate capacity in case of icing at culverts, at least two pipes will be provided at each location. The lower one will be located at ground surface, with the bottom of the upper pipe being set above the top of the underlying pipe. Where potentially severe icing conditions are identified, several culverts will be provided in "stacked" configuration.

e) DRAINAGE AND EROSION CONTROL MEASURES SPECIFIED ON ALIGNMENT SHEETS

Design will be refined prior to construction as detailed field information is obtained. Where necessary, minor modifications to the various drainage and erosion control measures constructed can be made prior to operation of the pipeline based on observations of their effectiveness during the inactive period after construction and before operation.

On the alignment sheets, each segment of the pipeline has been assessed with respect to drainage and erosion problems and has been assigned one of a number of drainage and erosion control categories.

The drainage and erosion control categories on the alignment sheets are based on the following three factors:

- Average surface slope and length, along and across the right-of-way.
- Terrain type which defines the soil type at ground surface.
- Existing drainage patterns.

The categories have been designated by a code, thus: "EC-NL" where EC stands for erosion control, N = type of control measure, L = maximum spacing of the breaks in the backfill mound along the segment.

Along most of the pipeline route the character (N) has been determined as indicated in the following table:

Type of Soil	Average Slope Along Segment	
	0° to 3°	Greater than 3°
Erodible Soils	EC-1	EC-2
Non-Erodible Soils	EC-3	EC-4

Where special measures are required EC-5, EC-6, EC-7, and EC-8 have been used as described later.

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Designations of minimum break spacing (L) for each segment has been based on the intensity of drainage courses crossing the pipeline as determined from the air photos. The values assumed at this stage are:

Category (L)	A	B	C	D
Minimum Spacing (ft.)	50	100	200	500

Where a segment of the pipeline crosses numerous "streams" (shallow drainage courses, requiring erosion control EC-7L for cut-graded slopes) two erosion control measures have been specified on the alignment sheets thus: EC-2L, EC-7L. The following is a brief description of the various drainage and erosion control categories called up on the alignment sheets:

- Category EC-1L

This category covers erodible soils in both permafrost and non-permafrost areas. Erosion control measures will only be required on the lower portions of slopes on gently rolling terrain and on gently sloping ground. The extent will depend on the size and characteristics of the upslope watershed. The measures will consist of protection of the end of the backfill mound and ground surface at mound breaks. Where the pipe is oriented within 10 degrees of the direction of the dip of the slope, breaks in the backfill mound will not be used and surface run-off will be deflected into virgin ground on the edge of the right-of-way by diversionary dikes in chevron formation. Riprap and downslope obstructions will only be required where surface runoff is expected to be very large.

- Category EC-2L

This category covers erodible soils in slopes of over three degrees. The drainage and erosion control measures will be generally similar to those for category EC-1L except that only the crests of slopes will not require protection. The upslope side of the backfill mound will be protected and spacing of breaks will be frequent. Diversion dikes will be located at closer spacing than for EC-1L. Drainage ditches will be used on the upslope side of the dikes in areas not subject to thaw settlement. Riprap and downslope obstructions will be placed at all breaks in the backfill mound.

- Category EC-3L

Since the ground surface included in this category is flat or gently sloping and is essentially non-erodible, the drainage and erosion control measures will only require breaks in the backfill mound at the bottom of slopes where surface run-off will be large. All diversion dikes will have a deep upslope ditch in non-permafrost terrain. Riprap and downslope obstructions will not be required.

- Category EC-4L

This category covers ground which slopes at more than three degrees in non-erodible soils. The measures will be the same as for Category EC-3L except that diversion dikes, ditches and down slope obstructions will be used to reduce the velocity of surface run-off. Riprap at breaks in the

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backfill mound will be required at low points.

- Category EC-5L

This category is required only where the pipeline crosses alluvial fan deposits (AFD) or alluvial cone deposits (ACD) and the present water channels are unstable. The solution will be to bury the pipe to such depth that exposure of the pipe due to the shifting drainage courses will not occur.

- Category EC-6L

This category applies to those lengths of the pipeline located on steep side slopes where excavation will be necessary to form a working surface during pipe installation. This method of construction is limited to non-permafrost terrain and permafrost terrain not susceptible to thaw settlement.

- Category EC-7L

This specification is intended for use in both permafrost and non-permafrost areas where some degree of cut-grading is essential in order to permit passage of construction equipment over severe changes in gradient. Such topographical conditions may be encountered at steep scarps and at deeply incised watercourses. The height of the excavated faces will rarely exceed 15 feet. Such excavations will generally be backfilled to a stable slope with granular or suitable native material. A terraced drainage way along the centre of the cut section will be constructed consisting of diversion dikes in permafrost terrain and a combination of ditches and diversion dikes in non-permafrost terrain. The structures will, where necessary, be lined with coarse granular soil.

- Category EC-8L

This specification may be applied in permafrost terrain to low-lying peat-filled areas of relatively level gradient where drainage patterns may be sensitive to interruption by construction of the backfill mound. More frequent or wider breaks than specified in other categories may be provided. Since buoyancy must be overcome in these locations, either the pipe will be weighted or granular backfill will be used where there is adequate lateral support from the sides of the ditch.

- Revegetation Specifications

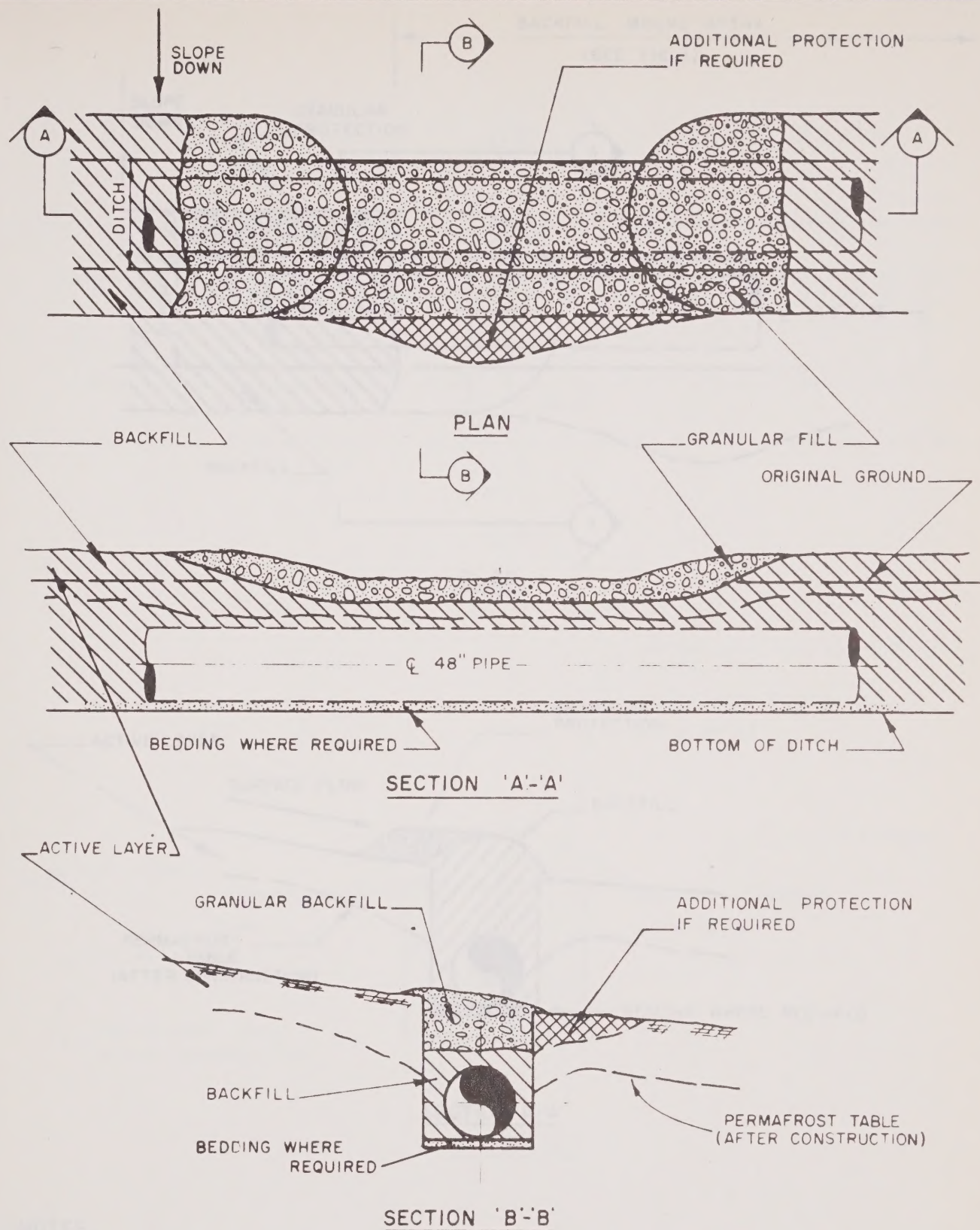
Extensive research has been carried out in revegetation techniques particularly at the test facilities at Sans Sault, Norman Wells, and Prudhoe Bay. As a result, specifications have been developed to cover the seed mixture required for the various ground conditions which will be encountered along the route, together with other measures required to re-establish the vegetation. An example of the coding used for the revegetation measures on the alignment sheets for the portion of the route between Fort Good Hope and the 60th Parallel follows: Proposed Specifications* For Right-of-Way Revegetation; Fort Good Hope to 60th Parallel.

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EXAMPLE CODING AND REVEGETATION SPECIFICATIONS*
FORT GOOD HOPE TO 60th PARALLEL

Code	Site Description	Approximate Seed Mix	Rate/acre
2-V-1	Dry, very well drained	Boreal Creeping Red Fescue	- 15 lb/ac
		Common Kentucky Bluegrass	- 10 lb/ac
		Meadow Foxtail	- 5 lb/ac
		Climax Timothy	- 2.5 lb/ac
		Revenue Slender Wheatgrass	- 15 lb/ac
		Frontier Reed Canarygrass	- 5 lb/ac
		Native Grasses	- 2.5 lb/ac
2-V-2	Moist, moderately to well drained	Boreal Creeping Red Fescue	- 10 lb/ac
		Common Kentucky Bluegrass	- 10 lb/ac
		Meadow Foxtail	- 10 lb/ac
		Climax Timothy	- 10 lb/ac
		Revenue Slender Wheatgrass	- 2 lb/ac
		Frontier Reed Canarygrass	- 10 lb/ac
		Native Grasses	- 5 lb/ac
2-V-3	Wet, poorly drained	Boreal Creeping Red Fescue	- 5 lb/ac
		Common Kentucky Bluegrass	- 10 lb/ac
		Meadow Foxtail	- 15 lb/ac
		Climax Timothy	- 10 lb/ac
		Frontier Reed Canarygrass	- 10 lb/ac
		Native Grasses	- 5 lb/ac
2-V-4	Wet, granular fill in ditch	As per 2-V-1	
2-V-5	Slope without shrub cover	Peg down erosion control mat. Seed combination of 2-V-2.	
2-V-6	Slope with shrub cover	Peg down erosion control mat with available willow and alder cuttings. Seed combination of 2-V-2.	
2-V-7	Slope with breaker dikes	Hand plant available willow and alder cuttings on upslope side of dikes. Seed combination of 2-V-2.	

*The Applicant is continuing its studies of revegetation procedures and this table will be updated if required as additional data become available.



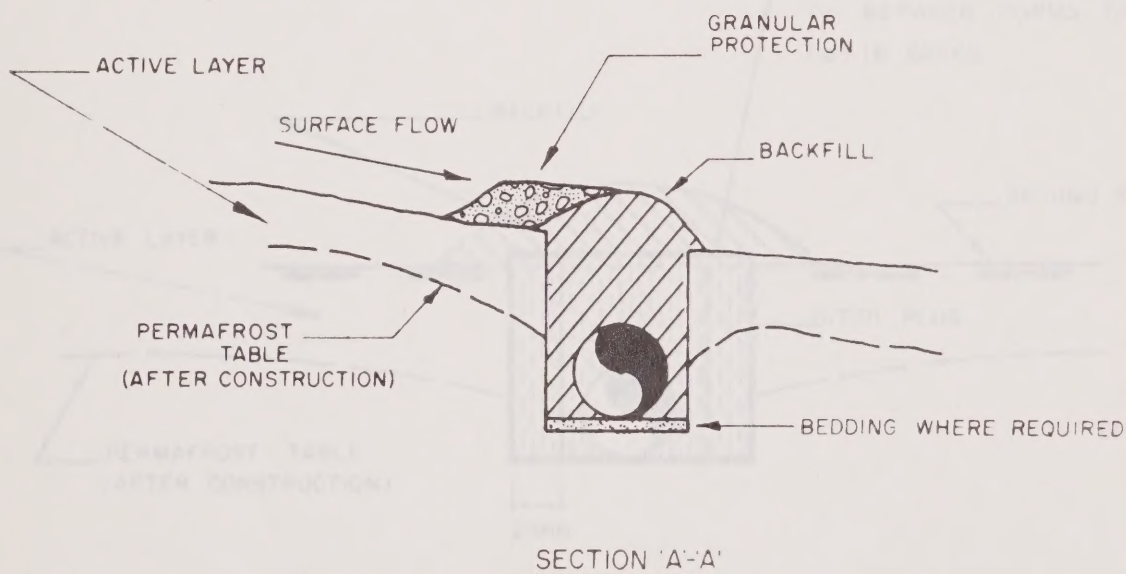
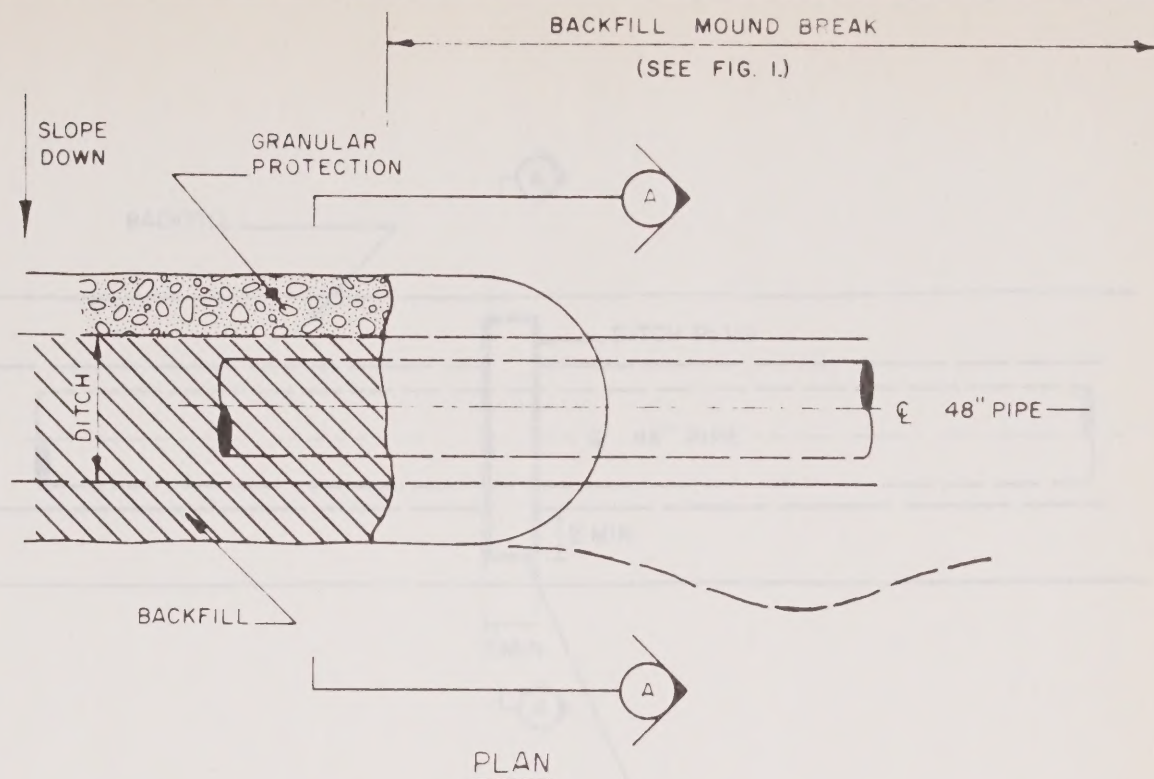
NOTES,

SURFACE OF BACKFILL WILL BE REVEGETATED

DRAINAGE AND EROSION CONTROL BACKFILL MOUND BREAK

FIGURE 1

8.b.1.3.8.



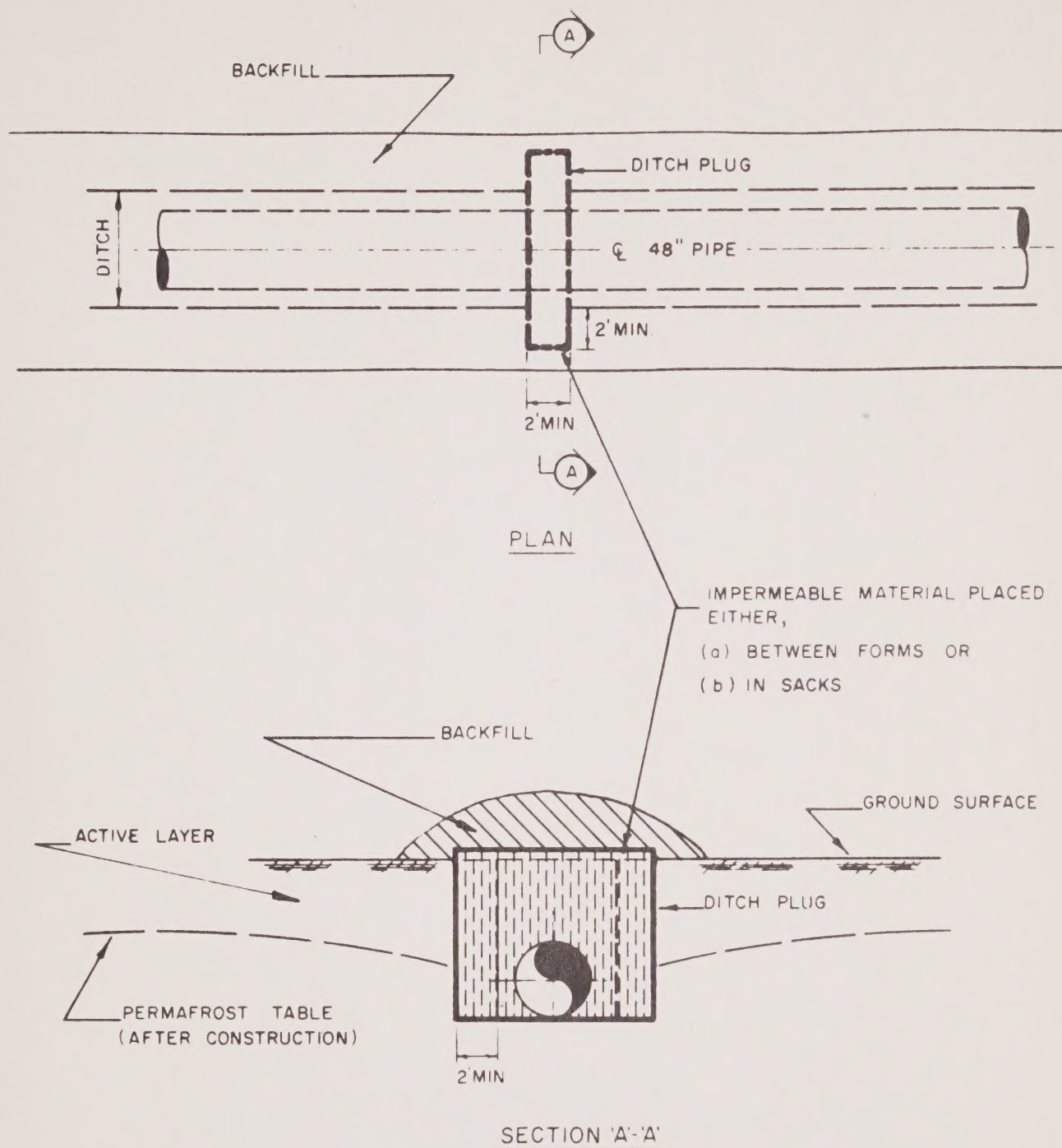
NOTES;

- I. SURFACE OF BACKFILL WILL BE REVEGETATED

DRAINAGE AND EROSION CONTROL
GRANULAR PROTECTION OF
BACKFILL MOUND

FIGURE 2

8.b.1.3.8



NOTE ;

SURFACE OF BACKFILL WILL BE
REVEGETATED

DRAINAGE AND EROSION CONTROL
DITCH PLUG

FIGURE 3

8.6.13.8

APPENDIX 2

CULVERT DESIGN AND INSTALLATION

TO

ENSURE FISH PASSAGE

1. INTRODUCTION

Only five streams are planned to be crossed by permanent roads constructed by the Applicant. These five streams are listed in Table 1. Of these, there are only two where fish were located by McCart et al. (1974). All streams to be crossed by permanent roads will be examined again prior to construction, and where it is necessary to design a culvert for fish passage, the following design and other considerations, listed in paragraphs 2 to 4, will be applied.

2. DESIGN CONSTRAINTS

- To preserve as closely as possible natural stream bed conditions, corrugated steel pipe-arches, the inverts being back-filled with 4-6 inches of crushed rock or gravel, will generally be used.
- Culverts will be placed below streambed grade with the inverts backfilled such that no exit or entrance drop-fall can develop.
- Culvert slope will be the average slope of the natural stream bed in the vicinity.
- Culvert lengths will be as short as practicable.
- The limiting water velocity for a culvert will be established after a detailed investigation of each site. Factors considered will include the length and species of fish to be accommodated, and natural flood velocities at the site. The cross-sectional area of the culvert will be selected such that the velocity in the culvert, except during the design flood, does not exceed the limiting velocity.

- The delay during which the limiting velocity may be exceeded will be a maximum of 7 days.

3. INSTALLATION CONSTRAINTS

- Installation will be scheduled to avoid spawning periods. Where sedimentation sufficient to significantly disturb a spawning bed may occur, construction will be timed to follow the hatching period.
- Since erosion can threaten the integrity of a river crossing structure as well as have an undesirable environmental effect, measures will be incorporated to minimize its occurrence. Adequate drainage structures and rip-rap protection of erodible slopes will be provided.

4. ESTIMATION OF THE DESIGN FLOOD

Where flood frequencies can be assigned, 1:50 annual flood will be used when overtopping is a consideration, consistent with the criteria used by the Department of Public Works. A risk analysis for fish passage requires further study of the relationship between spawning times and flood peaks.

For preliminary design, flows will be estimated from a drainage area-runoff envelop curve based on maximum recorded flows and rainfall in Alaska and Northern Canada. For final design, various synthetic and regional hydrological techniques, augmented by appropriate field measurements will be used to refine the estimates.

TABLE 1
Streams Crossed by Permanent Roads

Section	Approx Milepost	Approx Road Length (miles)	Presence of Fish	Streams Crossed
Richards Island to Travaillant Lake		no crossings proposed		
Travaillant Lake to 60th parallel	179	7	Probable	tributary to Thunder River
	357	1	Yes	tributary to Oscar Creek
	533	4	Yes	unnamed creek - north fork (5 mi. south of Ochre River)
	620	7	No	unnamed intermittent creeks
	710-720	10	No	unnamed intermittent creeks
Prudhoe Bay to Travaillant Lake (Coastal)		no crossings proposed		

Because the design curve is based on maximum recorded flow values, a frequency cannot be assigned to the curve. Although the true frequency is no doubt much lower than 1:50, this value will be assumed for preliminary design.

REFERENCE

McCart, P., W. Griffiths, C. Gossen, H. Bain and D. Tripp, 1974.
Catalogue of lakes and streams along routes of the proposed gas
pipeline from the Alaskan/Canadian border to the 60th Parallel.
CAGSL Biological Report Series. Vol. XVI.

APPENDIX 3

ESTIMATION OF ALLOWABLE FLOW THROUGH A MOUND BREAK

$$Q = 1.48 \times K \times L \times H^{3/2}$$

(1)

where Q = discharge in cfs
 K = coefficient of discharge
 L = length of break in feet
 H = height of water above the break in feet

The value of K is determined by the shape of the break. For a rectangular break, K is 1.48. For a triangular break, K is 1.0. For a parabolic break, K is 0.6. For a semi-elliptical break, K is 0.4. For a semi-circular break, K is 0.3. For a semi-elliptical break with a flat top, K is 0.5. For a semi-elliptical break with a rounded top, K is 0.4. For a semi-elliptical break with a pointed top, K is 0.3. For a semi-elliptical break with a flat top and a rounded bottom, K is 0.4. For a semi-elliptical break with a pointed top and a rounded bottom, K is 0.3. For a semi-elliptical break with a flat top and a pointed bottom, K is 0.4. For a semi-elliptical break with a pointed top and a pointed bottom, K is 0.3.

The following discussion is to give an appreciation of the relationships which will influence the design of a mound break. An approximate equation is developed relating grain size of the material used to construct a mound break to flow that the break can withstand without excessive scouring. This result is used to estimate the size of catchment area from which a mound break can safely collect flow.

A certain amount of removal and replacement of backfill material can be expected during the life of a mound break, depending on the sequence of flows which occur. The acceptable scour at a break may be determined by geothermal or buoyancy considerations but for the purposes of this exercise it is assumed that the levels of scour must not exceed 2.5 feet, the present level of minimum cover. If more scour is expected a minor stream crossing, rather than a simple mound break, may be required.

Scour has been related empirically to regime depth (NESCL, 1974b) by the following equation:

$$d_r + d = Z d_r \quad (1)$$

where d_r = regime depth

Z = a factor which ranges from approximately 1.4 to 4.0

d = depth of scour

Regime depth is the average depth of a "regime channel", that is, a channel which is stable over a long period of time with respect to the spectrum of flow it is receiving.

The values for Z vary from one physical situation to another. Because of the complex flow pattern which may occur at a mound break and the wide variety of circumstances under which mound breaks will be used, it is likely that the most severe scour conditions could develop from place to place and time to time. Therefore the maximum value for Z of 4.0 is probably the most appropriate choice from the given range. Therefore, since the depth of scour must be less than 2.5 feet:

$$d_r = d/(Z - 1)$$

$$= (2.5)/3.0$$

$$= 0.8 \text{ feet}$$

which establishes the allowable depth of flow through a mound break.

By applying the regime depth equation (NESCL, 1974b) and assuming negligible charge in the break flow:

$$q^2 = 27.5 D_{50}^{0.5} \quad (2)$$

where: q = discharge in cfs per unit breadth of flow

D_{50} = median grain size of backfill material in feet

Therefore

$$Q^2 = 27.5 D_{50}^{0.5} B^2 \quad (3)$$

where Q = total flow through mound break

B = break width

However, B must also satisfy the regime width equation

$$B = 1.8 Q^{0.5} \quad (4)$$

Therefore

$$Q = 89 D_{50}^{0.5} \quad (5)$$

which estimates the allowable flow through a mound break. Typical values for D_{50} are between 0.1 and 0.2 feet which correspond to values for Q of 28 to 40 cfs.

Equation (5) can also be used to estimate the size of catchment area which can be drained by a mound break. A preliminary estimate for design flow from small catchment areas is given in Volume I of the Reference Book of Water Crossings (NESCL, 1974a) as

$$Q_D = 300 A \quad (6)$$

where Q_D = design flood in cfs

A = drainage area in square miles

Substituting (6) in (5) gives

$$A = .3 D_{50}^{0.5}$$

The range of values for D_{50} of 0.1 - 0.2 feet gives a range for A of 0.09 - 0.13 square miles. Therefore, the size of a catchment area which can be drained by a mound break is of the order of 0.1 square miles.

REFERENCES

Northern Engineering Services Company Limited, 1974a, Reference Book of Water Crossings, Volume I - Hydrology, prepared for Canadian Arctic Gas Study Limited.

Northern Engineering Services Company Limited, 1974b, Reference Book of Water Crossings, Volume II - River Crossing Design, prepared for Canadian Arctic Gas Study Limited.

